



Particle Physics Division Mechanical Department

Engineering note number:

Date: 12/18/2001

Experiment	NuMI
Project	Horn 1 Module Main Frame
Author(s)	Rafael Silva (FNAL) <i>12/18/2001</i>
Reviewer(s)	Ang Lee (FNAL) <i>1/16/02</i>
Abstract	Structural analysis of Horn 1 Module Main Frame.

Summary

1. Overview
2. Structural Analysis:
 - 2.1. Allowable Stresses
 - 2.2. F.E.A. Of NuMI Horn 1 Module Mainframe
 - 2.2.1. Model
 - 2.2.2. Parameters Used
 - 2.2.3. Boundary Conditions
 - 2.2.4. Results
 - 2.3. Analysis Of Connections
 - 2.3.1. Welded Connections
 - 2.3.2. Bolted Connections
3. Technical Specification
4. Drawings

Appendix A – Lifting Hooks for Numi Horn Module (by Bob Wands)

1. Overview

NuMI Horn 1 is supported and located by a structural steel frame called Module. The basic design was developed by Tom Cygan in conjunction with Kris Anderson.

Module features:

- Provide structural support for NuMI horn 1 and remote position adjustment
- Provide radiation shielding
- Allow mounting and dismounting of horn from top of module mainframe away from highly radiated areas.
- Constructed with materials resistant to corrosion, heat, and radiation (stainless, nickel plated, "Graphalloy", etc).

Note: Horn is at -3.34321° from horizontal

Module components:

- Module mainframe
- Support arms
- Upstream and downstream horn support
- Upstream and downstream horn vertical and horizontal adjustment drive
- Cooling water tank
- Horn stand
- Cooling water supply/return/venting piping
- Electronic monitoring connector pods

This note addresses the structural analysis of the Module mainframe.

The Module mainframe is a welded carbon steel frame combining ASTM A36 carbon steel 3/8" plates and 10-inch plates, and ASTM A500 Gr.B 3/8" and 1/2" wall rectangular structural tubing. A bottom plate spans across the main body of the frame forming a box-like rigid structure with no top. The interior space of mainframe structure will be filled with solid steel shielding blocks which hang from above and are not supported by this structure and do not add to its overall weight. All exposed carbon steel surfaces will be skinned with #22 ga (.0293") stainless steel or protected with rust-inhibitors.

Each sidewall is made out of 2"x8"x3/8" tubing, 3/8" steel plates and one 4"x12"x1/2" tube, which creates a 2" internal step in the inside of the sidewalls for shielding purposes and it is flush outside. 1" x 12" ASTM A36 carbon steel plates form a step at the bottom of the inside of the endplates, also for shielding.

The inside of the sidewalls, including the inside of the 2"x8"x3/8" tubing and the space in between them, will be filled with grout. The 4"x12"x1/2" tube will be filled with steel bars.

An open box stainless steel structure formed by 2" and 2 1/4" plates to accept the strip line support module is welded to the downstream 10-inch plate. Lower end of upstream and downstream 10-inch plates are relieved for the mounting of linear transverse drive sub-assemblies.

I-DEAS 8 m4 : PARTICLE PHYSICS DIVISION : USER.rafael : /cadwhs/server03/ms_ra
Database: /cadwhs/server03/ms_rafael/hornl_module.mfi
View : VVIEW1
Task : Post Processing
Model: module_w_ss_slb
Active Study: DEFAULT FE STUDY
module_w_ss_slb

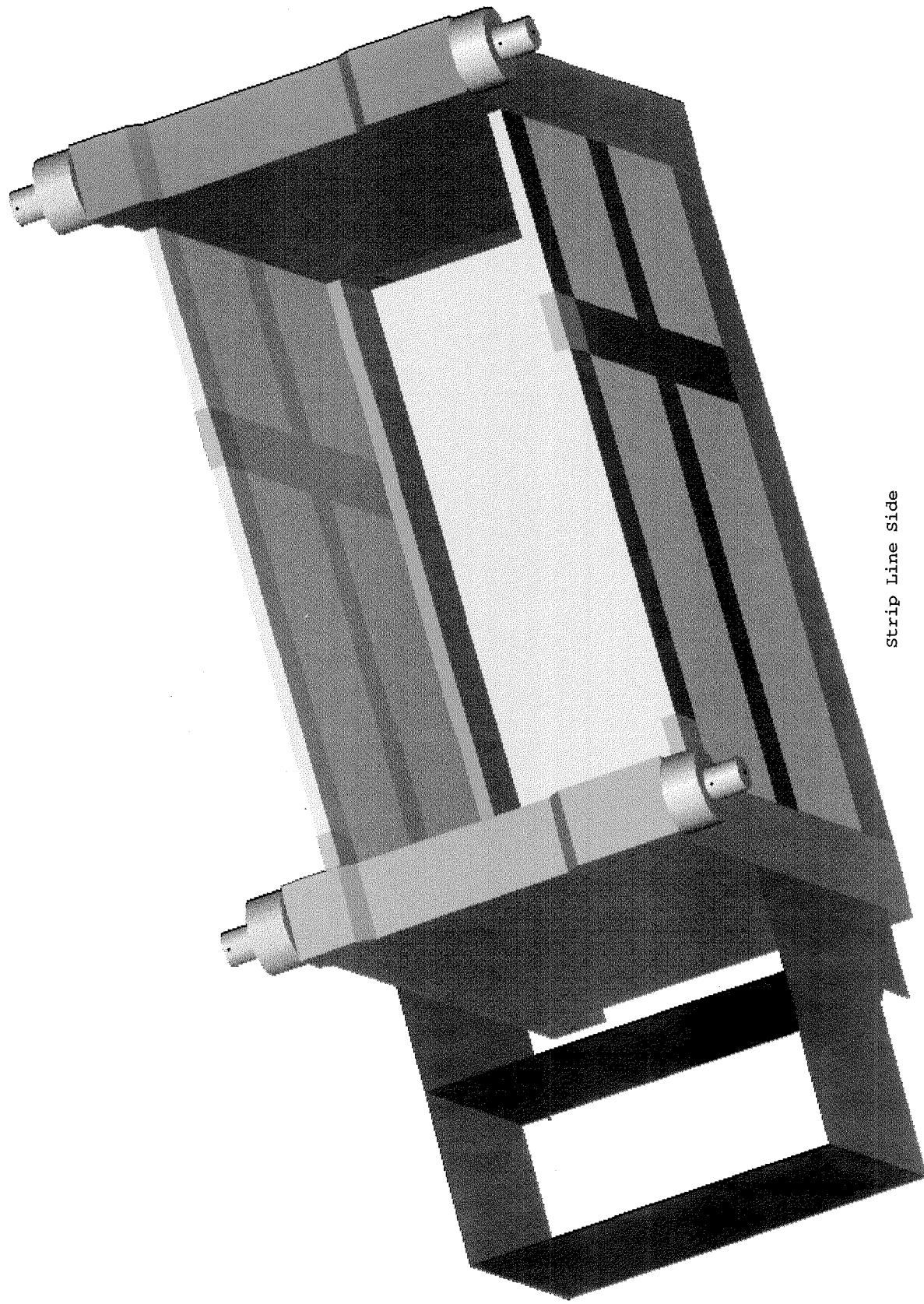
10-Dec-01 15:24:41

Units : IN

Display : No stored Option

Model/Part Bin: Main

Parent Part: module_w_ss_slb



Strip Line Side

The 10-inch plates have 50" deep counterbored and horizontally slotted holes for horn support main shaft. It eliminates radiation line of sight and allows for +/- 3/8" vertical and +/- 3/8" transverse horizontal main shaft movement. It also has vertical full-length holes for fastening drawbars for modular lower transverse linear bearing and drive sub-assembly and transverse drive shaft. Upstream and downstream full length counterbored holes are provided for cooling water supply, return, venting, and electronic monitoring wiring connections.

The Support arms are made out of 1045 HR carbon steel (diameters available up to 24") one-piece 4" diameter solid shaft bolted and pinned in place to a 10" diameter flange.

The NuMI Horn 1 module has to sustain its own weight, the horn and its components. It will be lifted by crane through its own hooks, which are analyzed separately.

2. Structural Analysis

In spite of the fact that the NuMI Horn 1 Module is not what would normally be described as a lifting fixture, this frame was analyzed and compliance with ANSI/ASME B30.20-1985 "Bellow-the-Hook Lifting Devices" standard and 1987 addenda was verified. The two basic design recommendations of this standard and its addenda are:

- Minimum design factor of 3 over the rated load, based on yield strength (20-1.22, p.21) and
- Load test with 125% of the rated load (20-1.4.2, p.22).

The load test will be limited to the NuMI hall crane capacity, which is 30 tons (about 120% of design load).

2.1. Allowable Stresses

Hand Calculations:

Stresses - individual stress components should be in accordance with the most stringent of the following codes:

- AA or AISC/ASD (whichever applicable)
- ASME B30.20

Stability - if compressive forces are present:

- AA or AISC/ASD (whichever applicable)

Finite Element Analysis:

Stresses:

- Maximum peak Von Mises stresses (nodal averaging) < 1/3 of the Yield Strength (based on ASME B30.20).
- Maximum peak shear stresses (nodal averaging) < 1/6 of the Yield Strength (based on ASME B30.20 and strength of materials theory).

This is very conservative, since localized stresses can be linearized and peak stresses maybe discarded. Nonetheless, it is safe.

Stability - if compressive forces are present:

- Buckling Load Factor (linear buckling) > 5 (see note below).

Published safety factors for buckling vary according to the application. A safety factor greater than 5 is comfortably above what is recommended by some very accepted references as, for instance, the ASME pressure vessel code (see sec. II, appendix 3, item 3-600 (c) (1), p.705). It addresses axial compression of thin cylinders which is experimentally known to be one of the cases that most diverges from buckling theories. Another example is the Aluminum Association standard (see tb. 3.3.3, p.17), which covers aluminum structures.

This note verifies the stresses in the most critical members and connections only. The minimum specified yield strength for the 10-inch plates is 32 ksi, for the other plates is 36 ksi and for the tubing is 46 ksi. The lift arms and couplings have even higher yield strengths.

For the 32 ksi plates:

- 1/3 of the Yield Strength = 10.7 ksi
- 1/6 of the Yield Strength = 5.3 ksi

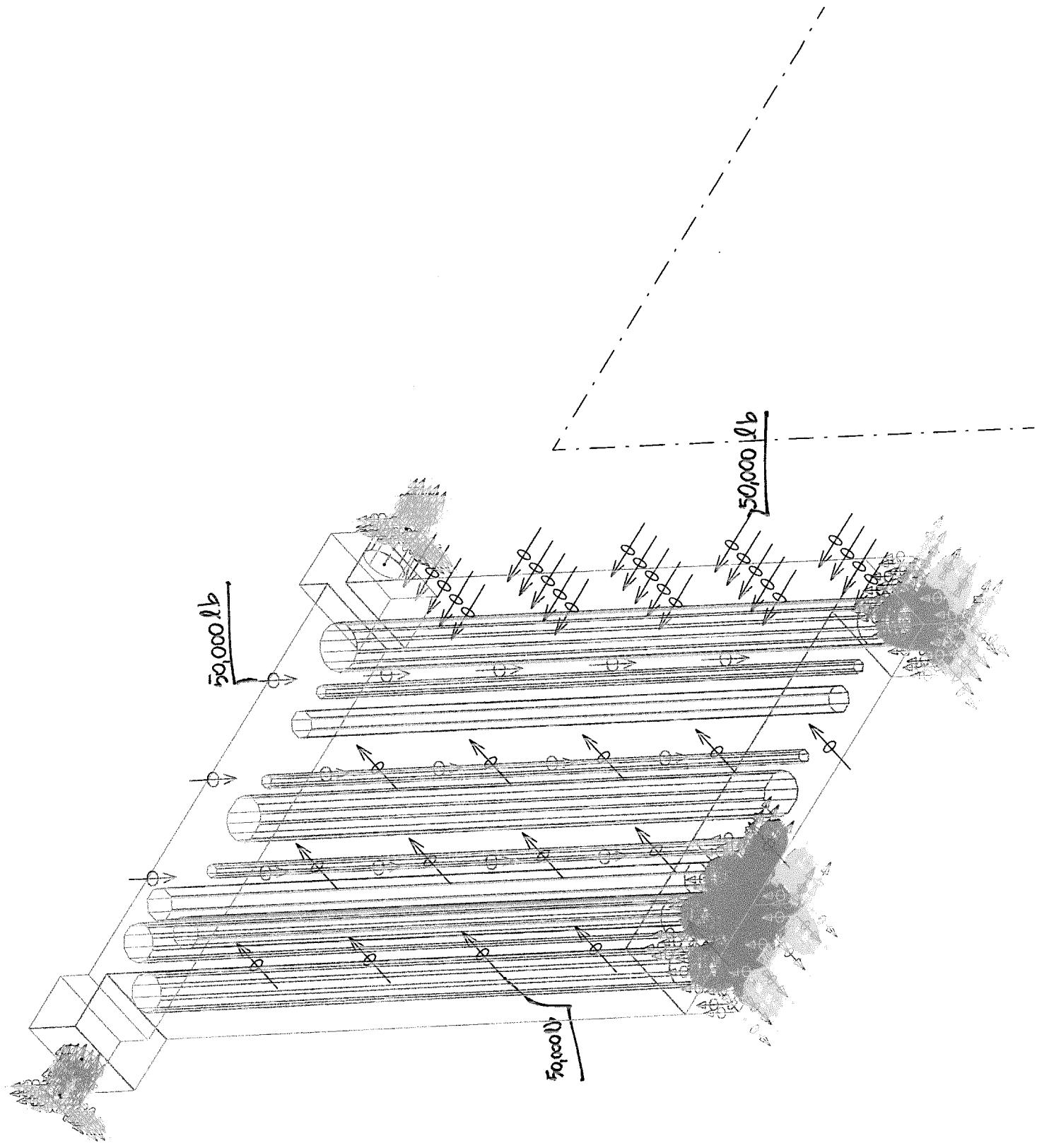
2.2. F.E.A. Of NuMI Horn 1 Module Mainframe

2.2.1. Model

First, a model of the 10-inch plate with holes (lots of elements) was compared with a model of the endplate without the holes. The plate without holes deflects 84% of what the plate with holes does. Applying that percentage to the Elastic Modulus gives 24,500ksi. So, for the analysis of the frame, a plate without holes was used and its Elastic Modulus was conservatively reduced to 20,000ksi (69%).

The frame model has the 10-inch plates created and meshed as solids. The plates are a mirror image of each other and they both have a reduced Young's Modulus to account for the holes. The sidewalls (plates and tubes), the strip line box and the bottom plate are shells. In reality, the top of the 10-inch plate is a separate component bolted to the bottom part. That top part is called "modtops" and, in this analysis, it is considered integral part of the end plates. Half of the support shaft was considered part of the "modtops" and the restraints were applied to the vertical external surface of these half-shafts or to the location of the hooks.

The bottom part of each one of the hooks is integral part of the mainframe. It was represented by 1 in plates following the geometry of the tubes attached to them.



```
RESULTS: 3 - B.C. 1, STRESS_-3, LOAD SET 1  
STRESS - VON MISES MIN: 6.99E+00 MAX: 5.53E+03  
DEFORMATION: 1- B.C. 1, DISPLACEMENT_-1, LOAD SET 1  
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 4.31E-03  
FRAME OF REF: PART
```

VALUE OPTION: ACTUAL

5 . 5 3 E + 0 3

4 . 9 8 E + 0 3

4 . 4 2 E + 0 3

3 . 8 7 E + 0 3

3 . 3 2 E + 0 3

2 . 7 7 E + 0 3

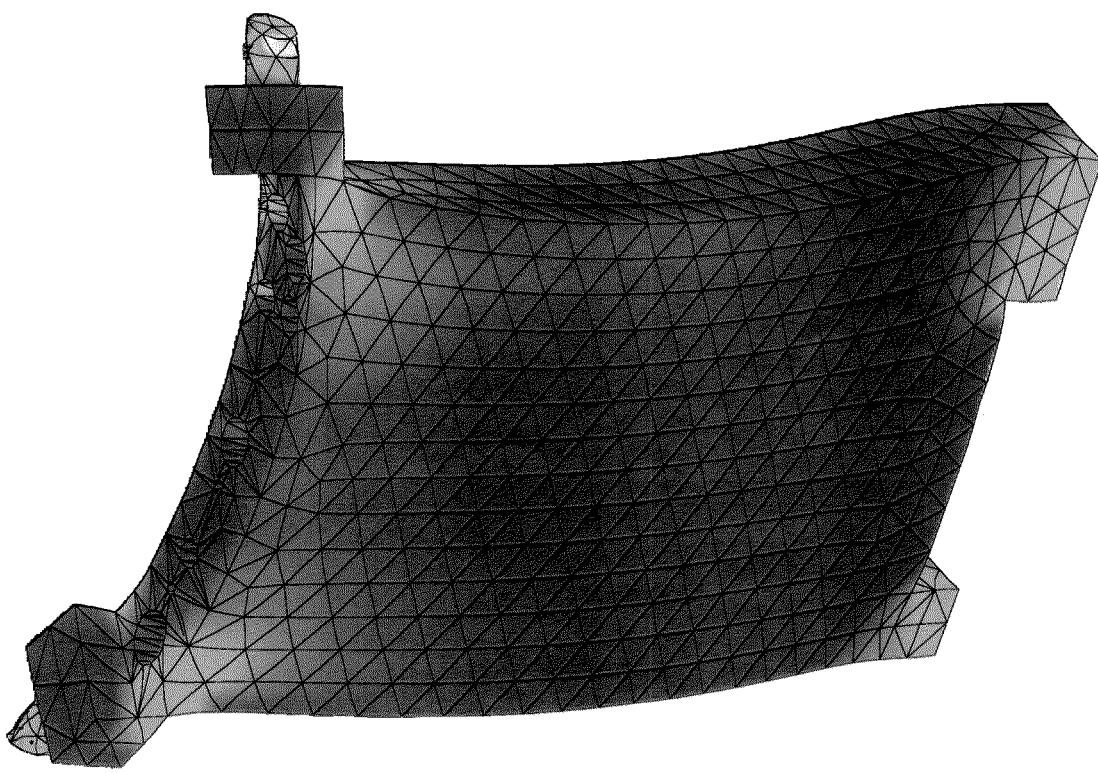
2 . 2 2 E + 0 3

1 . 6 6 E + 0 3

1 . 1 1 E + 0 3

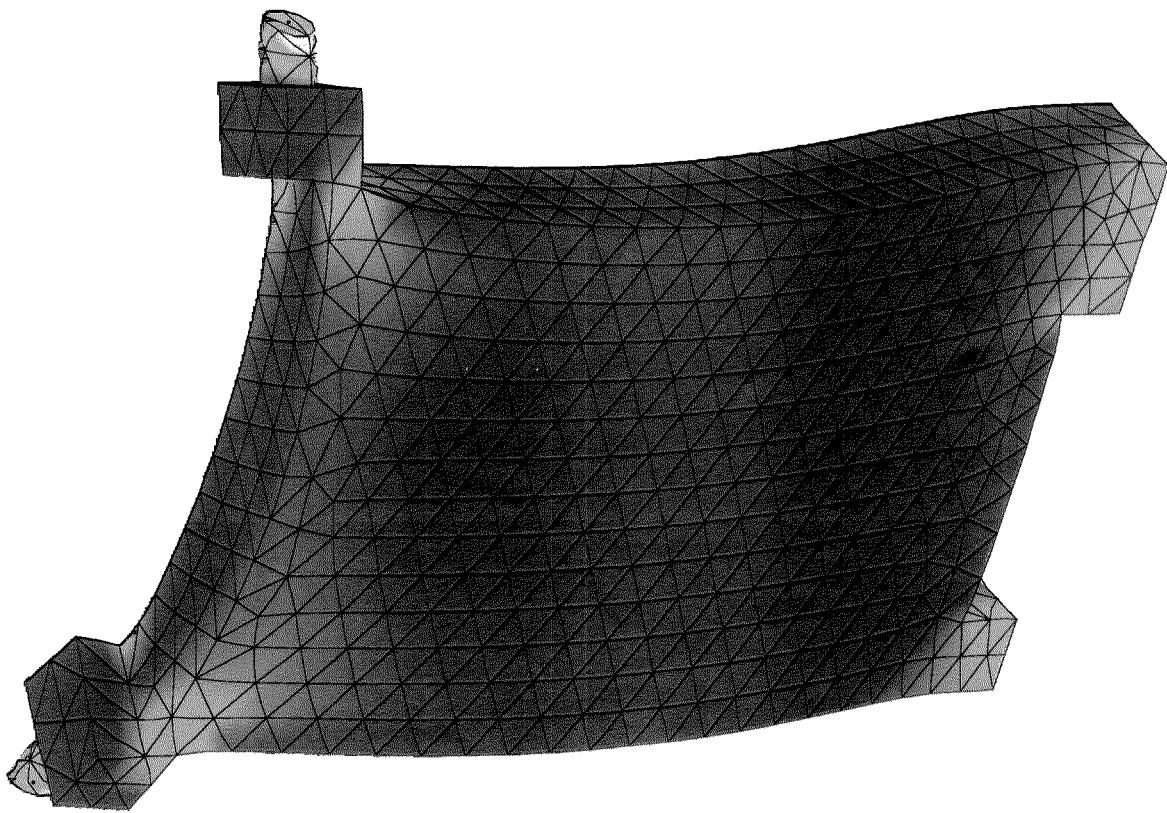
5 . 5 9 E + 0 2

6 . 9 9 E + 0 0



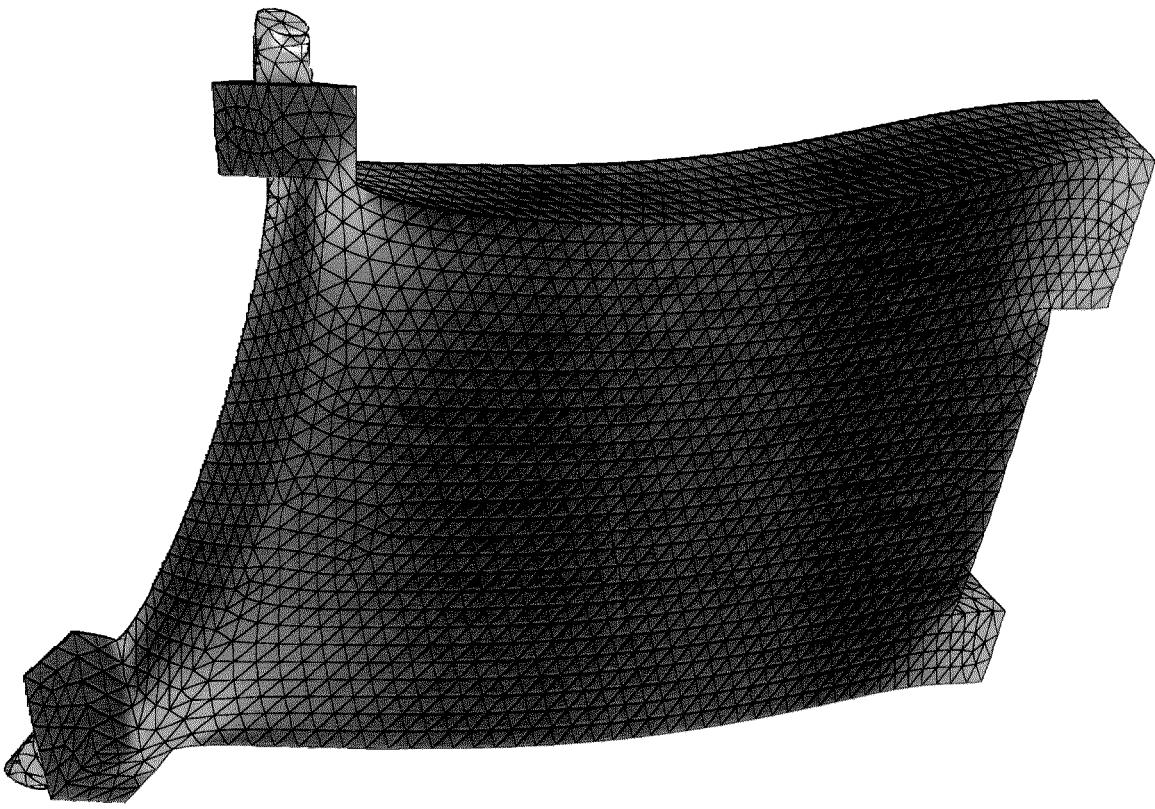
```
RESULTS: 3 - B.C. 1, STRESS_-3, LOAD SET 1  
STRESS - VON MISES MIN: 1.31E+01 MAX: 5.18E+03  
DEFORMATION: 1 - B.C. 1, DISPLACEMENT_-1, LOAD SET 1  
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 3.64E-03  
FRAME OF REF: PART
```

```
/cadwhs/server03/ms_rafael/h1module_mod  
VALUE OPTION: ACTUAL  
5.18E+03  
4.66E+03  
4.14E+03  
3.63E+03  
3.11E+03  
2.59E+03  
2.08E+03  
1.56E+03  
1.05E+03  
5.29E+02  
1.31E+01
```



```
RESULTS: 3 - B.C. 1, STRESS_3, LOAD SET 1  
STRESS - VON MISES MIN: 1.09E+01 MAX: 5.16E+03  
DEFORMATION: 1 - B.C. 1, DISPLACEMENT_1, LOAD SET 1  
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 3.68E-03  
FRAME OF REF: PART
```

```
5.16E+03  
4.65E+03  
4.13E+03  
3.62E+03  
3.10E+03  
2.59E+03  
2.07E+03  
1.56E+03  
1.04E+03  
5.26E+02  
1.09E+01
```



To analyze the connections, another model was used. For that, the original model was copied and the 10-inch plates were coated with a 3/8" thick shell providing means of obtaining the moments at these locations.

2.2.2. Parameters Used

- Program: SDRC I-DEAS v. 8m4 / Simulation.
- Analysis: Linear Statics
- Material properties -
 - All elements are the default generic isotropic steel:
 - density = 7.317372×10^{-4} lbf.sec²/in⁴
 - η = 0.29
 - Shell elements have E = 2.99938×10^7 psi (default)
 - Solid elements have E = 2.0×10^7 psi
- Elements:
 - Solids: solid parabolic tetrahedron with 4" average mesh size.
 - Shells: parabolic quad shell with 4" average mesh size.

2.2.3. Boundary Conditions

The operational load is estimated to be:

- Module main frame: 30,100 lb
- Components: 5,100 lb
- Horn 1: 1,000 lb
- Tank (full): 1,100 lb
- Strip line: 13,500 lb
- Total: 50,800 lb

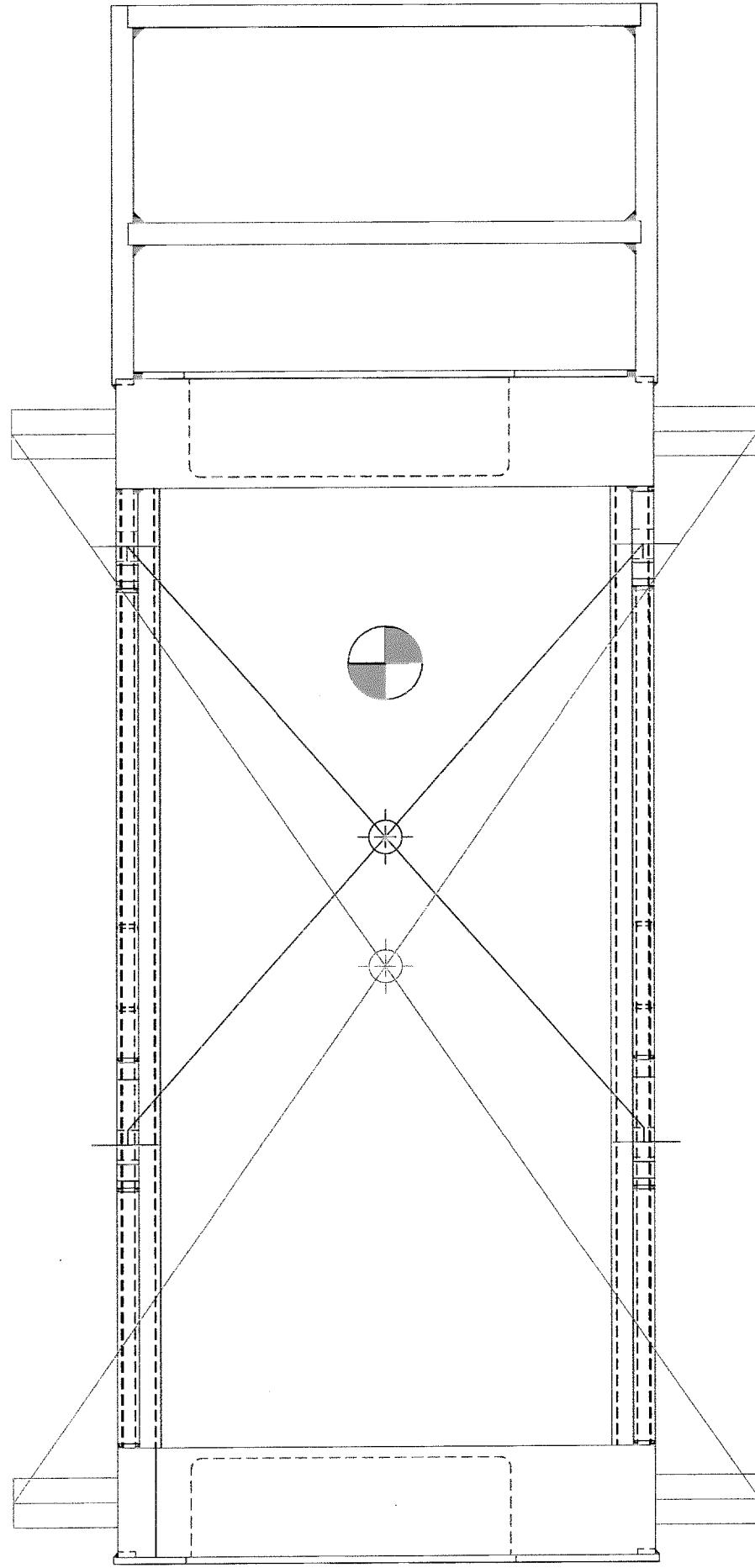
Just for reference, the estimated weight for the large module stand is 3,200 lb and for the lifting fixture is 1,500 lb.

For the model, the loads were:

- Weight of modeled steel parts = 32,580 lb (own weight)
- Contingency (by using g = 400 in/sec²) = 1,125 lb (extra)
- Total force on top of the strip line box = 13,520 lb (strip line)
- Total force inside the sidewalls = 1,885 lb (grout and steel)
- Total force on top of 10-inch plates = 7,200 lb (horn, components, tank)

The total vertical reaction is 56,290 lb and the reaction from the lateral load is 5,739lb.

The module may be supported by its arms or by its lifting hooks. It may be possible to support or lift the module through 3 points only but, because of the position of the center of gravity, 2 of the 3 points have to be located downstream.



2.2.4. Results

The maximum Von Mises and shear stress (ksi) and overall deflections (in) are indicated in the table bellow. For the linear buckling cases, the buckling load factor is indicated instead. Reactions are in kips.

Support Member	Number of Support Points	Linear Analysis Type	Boundary Conditions Set	Load Set	Restraint Set	Maximum Von Mises Peak Stress	Maximum Shear Peak Stresses	Maximum Deflection
Arm	4	Static	1 operational	1	7.96	4.27	0.011	
	3	Static						
	3	Buckling						BLF = 53.3
Hook	4	Static	4 operational	3	2.15	1.13	0.008	
	3	Static						
	3	Buckling						BLF = 91.0

Support Member	Number of Support Points	Upstream						Downstream						Total		
		Strip Line Side			Other Side			Strip Line Side			Other Side					
		Rx	Ry	Rz	Rx	Ry	Rz	Rx	Ry	Rz	Rx	Ry	Rz	Rx	Ry	Rz
Arm	4		9.7			4.5			13.6	3.4	5.4	28.5	-3.4	5.4	56.3	0.0
	3					13.9			23.7	3.3	5.4	18.7	-3.3	5.4	56.3	0.0
Hook	4		14.1			3.0			10.4	4.1	5.4	28.8	-4.1	5.4	56.3	0.0
	3					15.0			24.5	4.0	5.4	16.8	-4.0	5.4	56.3	0.0

As can be seen on the plots attached, only a few spots of the structure reach stresses above 1 ksi, which indicates concentration of stresses in those spots.

- Maximum peak Von Mises stresses < 10.7 ksi
- Maximum peak shear stresses < 5.3 ksi

Hence, the structure is OK.

I-DEAS 8 m4 : PARTICLE PHYSICS DIVISION : USER.rafael : /cadwhs/server03/ms_ra

04-Dec-01 11:53:20

Database: /cadwhs/server03/ms_rafael/horn1_module.mf1

View : 1, 1

Task : Post Processing

Model: module_w_ss_slb

Active Design: DEFAULT FE STUDY

/cadwhs/server03/ms_rafael/horn1_module.mf1

RESULTS: 3- B.C. 1. STRESS_3, OPERATIONAL LOAD
Stress - VON MISES MIN: 5.55E-01 MAX: 7.96E-03
DEFORMATION: 1- B.C. 1. DISPLACEMENT_1, OPERATIONAL LOAD
Displacement - MAG MIN: 0.00B+00 MAX: 1.09E-02
FRAME OF REF.: PART

VALUE OPTION: ACTUAL
SHNLL SURF: 9.98E+00

7.17D+0

6.37D+0

5.57D+0

4.78D+0

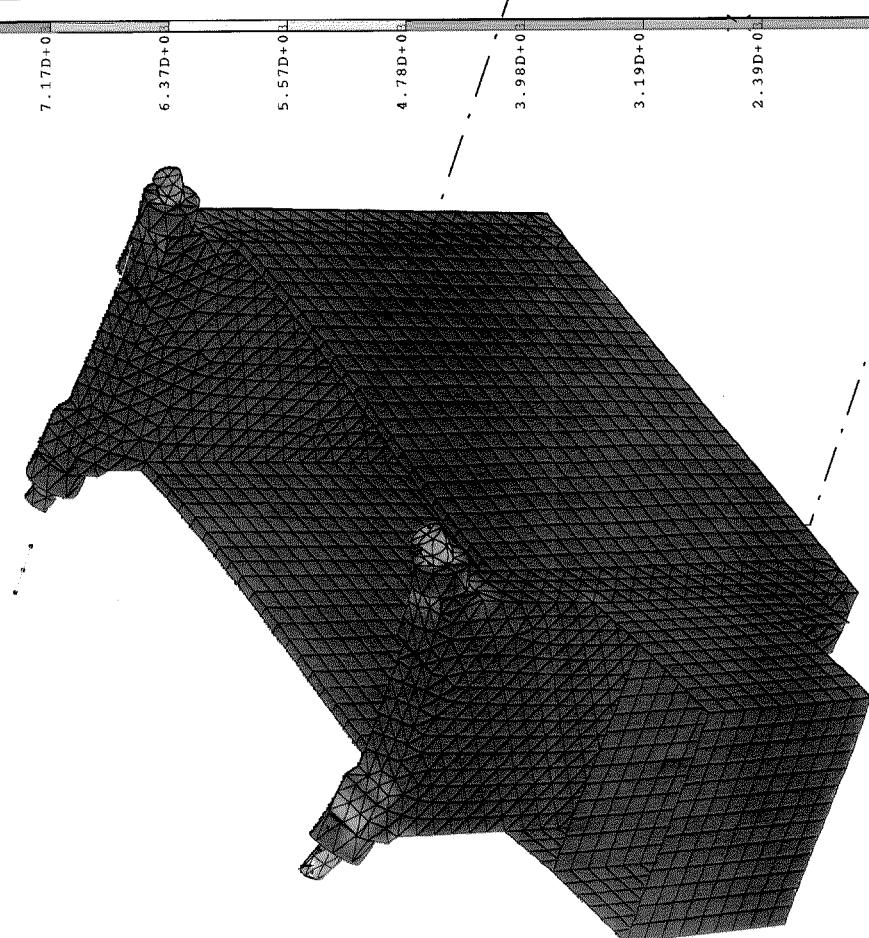
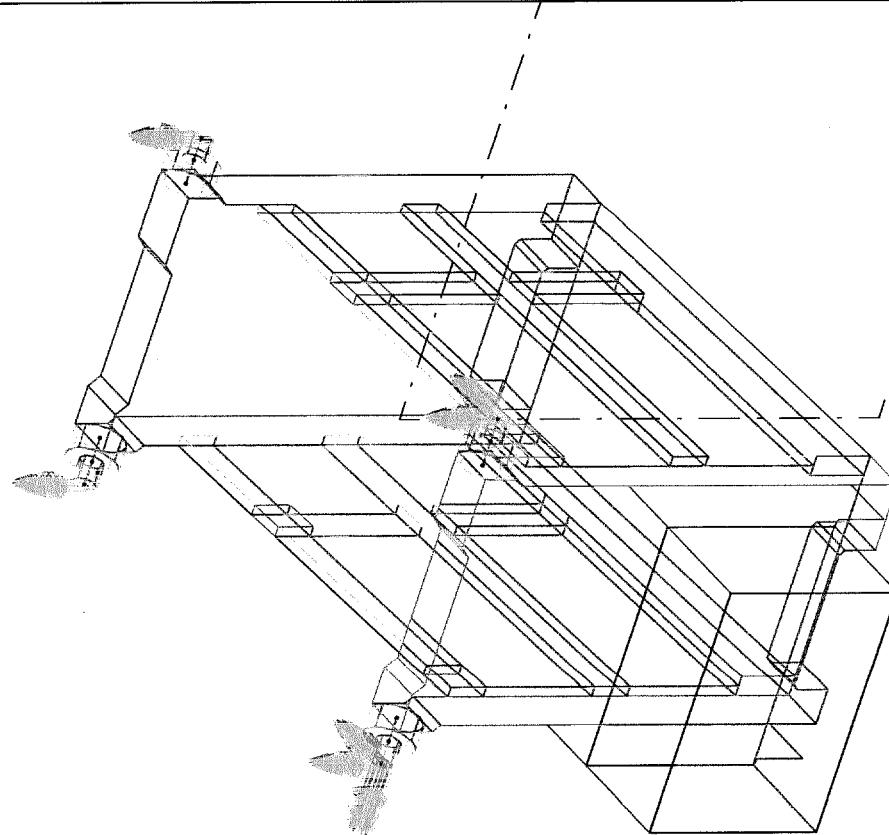
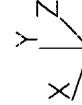
3.98D+0

3.19D+0

2.39D+0

1.59D+0

5.55D-0



I-DEAS 8 m4 : PARTICLE PHYSICS DIVISION : USER.rafael : /cadwhs/server03/ms_ra

10-Dec-01 14:05:55

Database: /cadwhs/server03/ms_rafael/horn1_module.mf1

View : 1, 1

Task : Post Processing

Model: module_w_ss_slb

Active Study: DEFAULT FE STUDY

/cadwhs/server03/ms_rafael/horn1_module.mf1

RESULTS: 7 - B.C. 2 ,STRESS_7, OPERATIONAL LOAD

Stress - VON MISES MIN: 9.10E-02 MAX: 9.95E+03

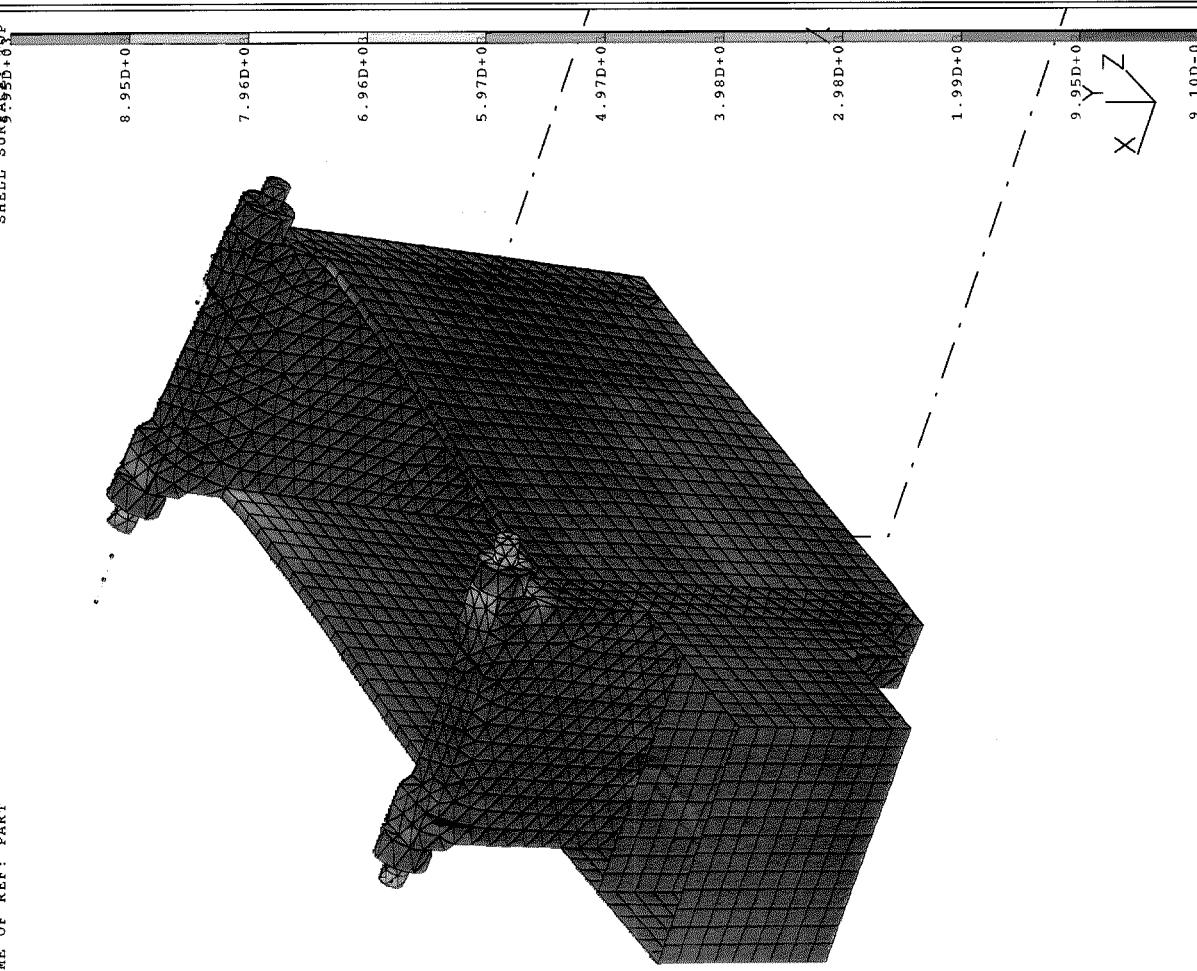
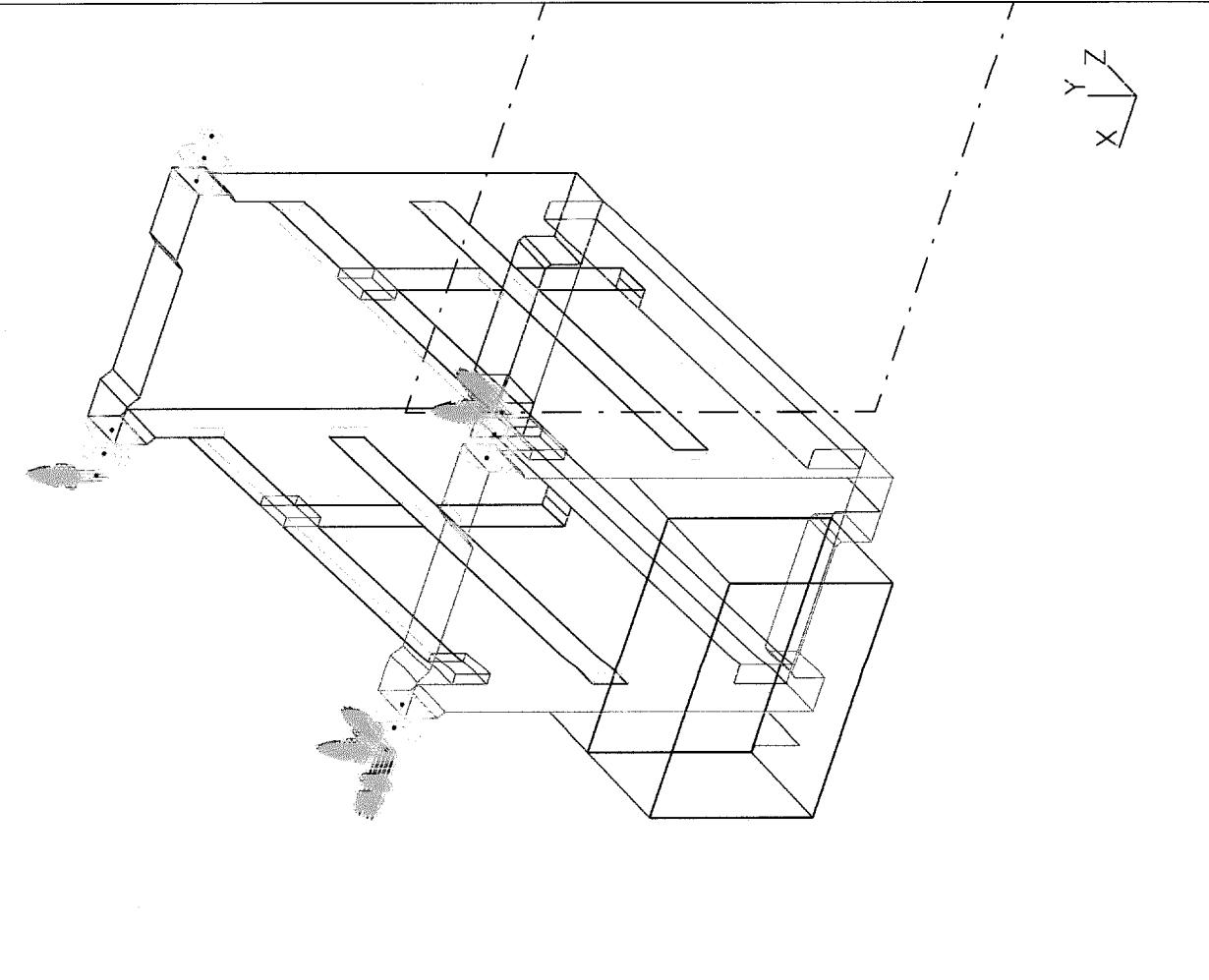
DEFORMATION: 5 - B.C. 2 ,DISPLACEMENT_5, OPERATIONAL LOAD

Displacement - MAG MIN: 0.00E+00 MAX: 7.19E-02

FRAME OF REF: PART

VALUE OPTION: ACTUAL

SHELL SURF: 656+09P



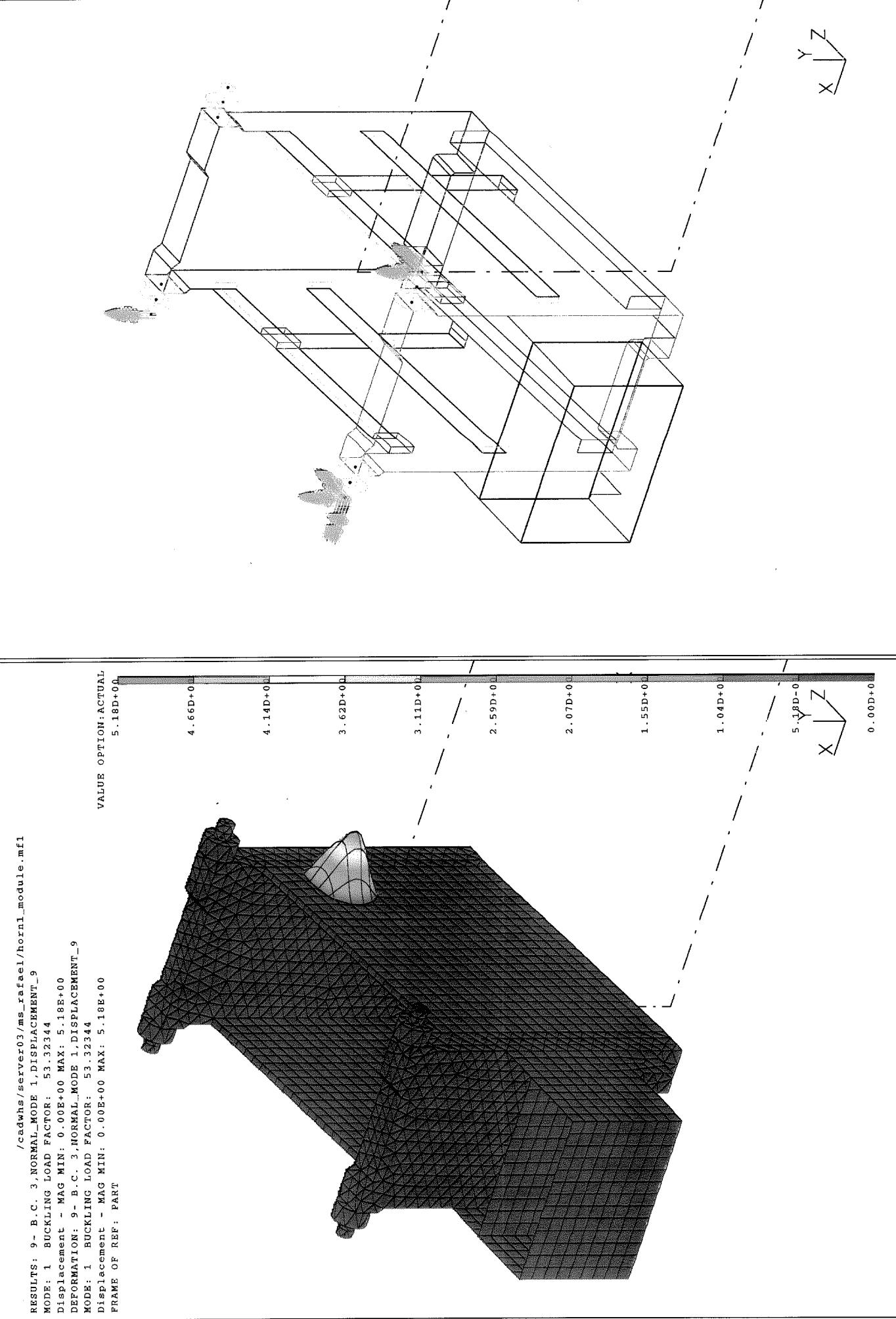
I-DEAS 8 m4 : PARTICLE PHYSICS DIVISION : USER.rafael : /cadwhs/server03/ms_ra

10-Dec-01 14:10:04

Database: /cadwhs/server03/ms_rafael/horn1_module.mfl
View : 1, 1
Task : Post Processing
Model: module_w_ss_slb

Active Study: DEFAULT FE STUDY

Units : IN
Display : none, none
Model/Part Bin: Main
Parent Part: module_w_ss_slb



I-DEAS 8 m4 : PARTICLE PHYSICS DIVISION : USER.rafael : /cadwhs/server03/ms_rafael

10-Dec-01 14:42:30

Database: /cadwhs/server03/ms_rafael/horn1_module.mf1

View : 1, 1

Task : Post Processing

Model: module_w_ss_slb

Active Study: DEFAULT FE STUDY

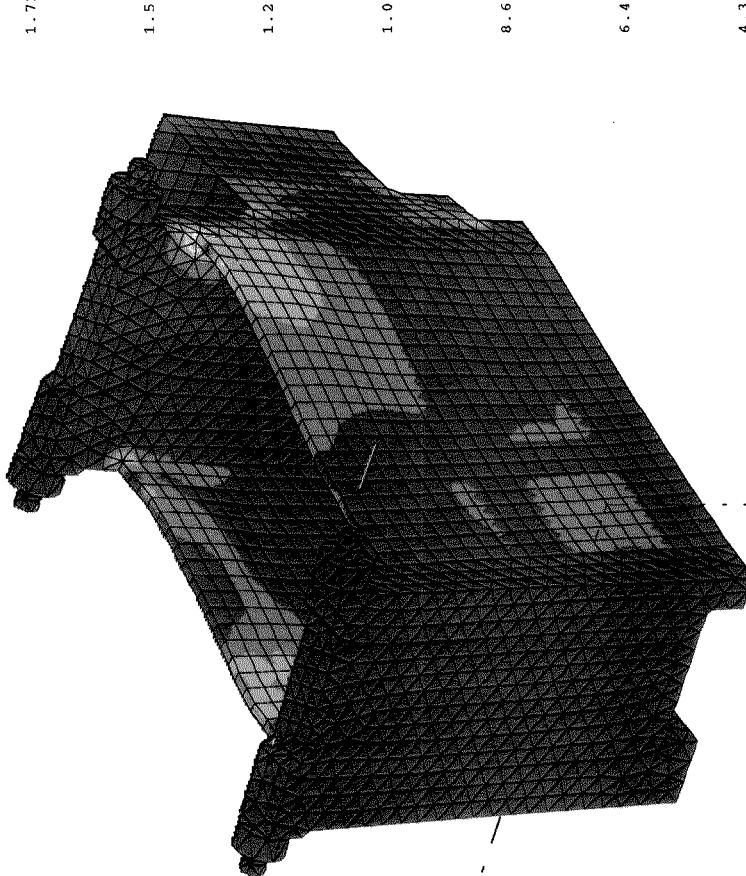
/cadwhs/server03/ms_rafael/horn1_module.mf1

Units : IN
Display : none, none
Model/Part Bin: Main
Parent Part: module_w_ss_slb

1

RESULTS: 14- B.C. 4-STRESS_14.OPERATIONAL LOAD
Stress - VON MISES MIN: 8.14E-02 MAX: 2.15E-03
DEFORMATION: 12- B.C. 4-DISPLACEMENT_12.OPERATIONAL LOAD
Displacement - MAG MIN: 0.00E+00 MAX: 7.92E-03
FRAME OF REF: PART

1.94D+0



1.72D+0

1.51D+0

1.29D+0

1.08D+0

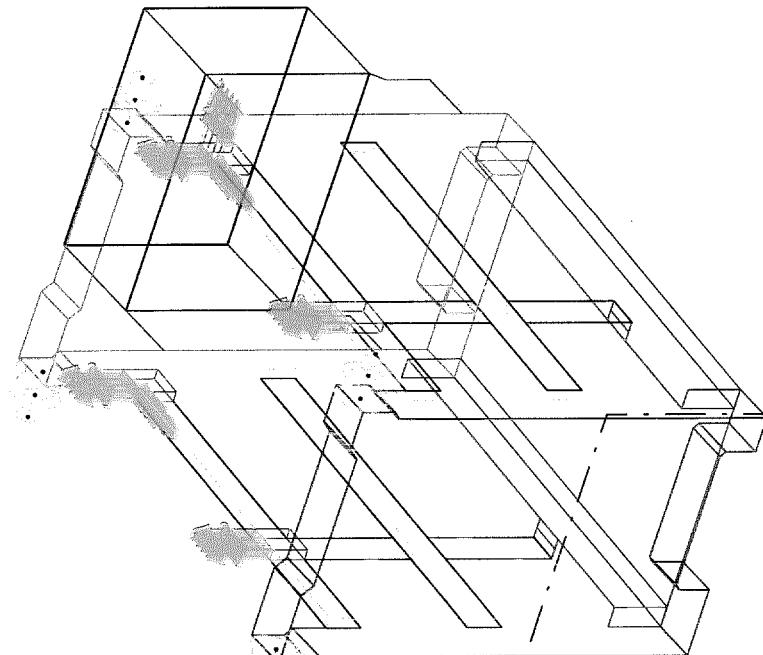
8.62D+0

6.46D+0

4.31D+0

2.16D+0
8.14D+0

X
Y
Z



10-Dec-01 14:45:22

I-DEAS 8 m4 : PARTICLE PHYSICS DIVISION : USER.rafael : /cadwhs/server03/ms_rafael

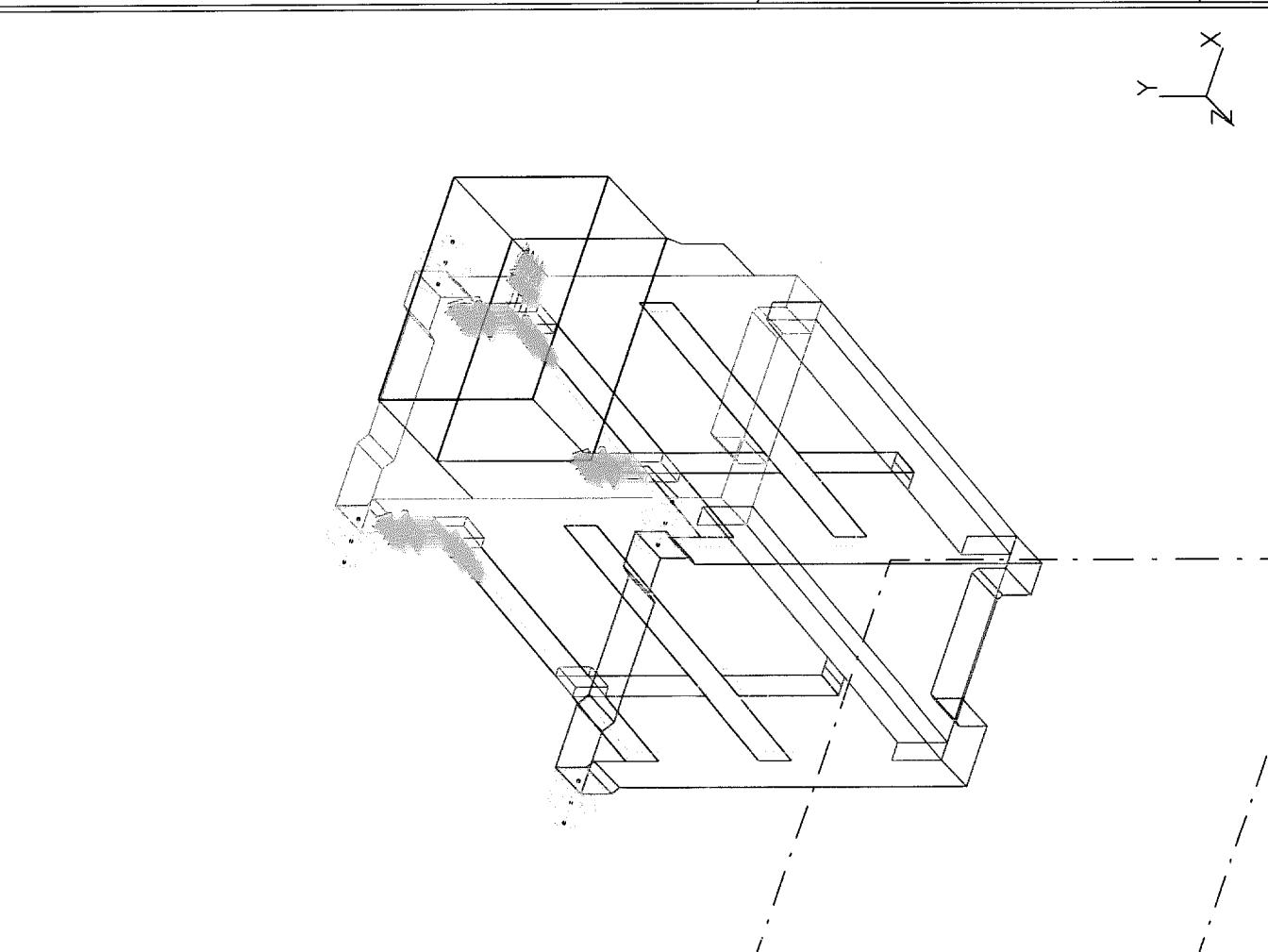
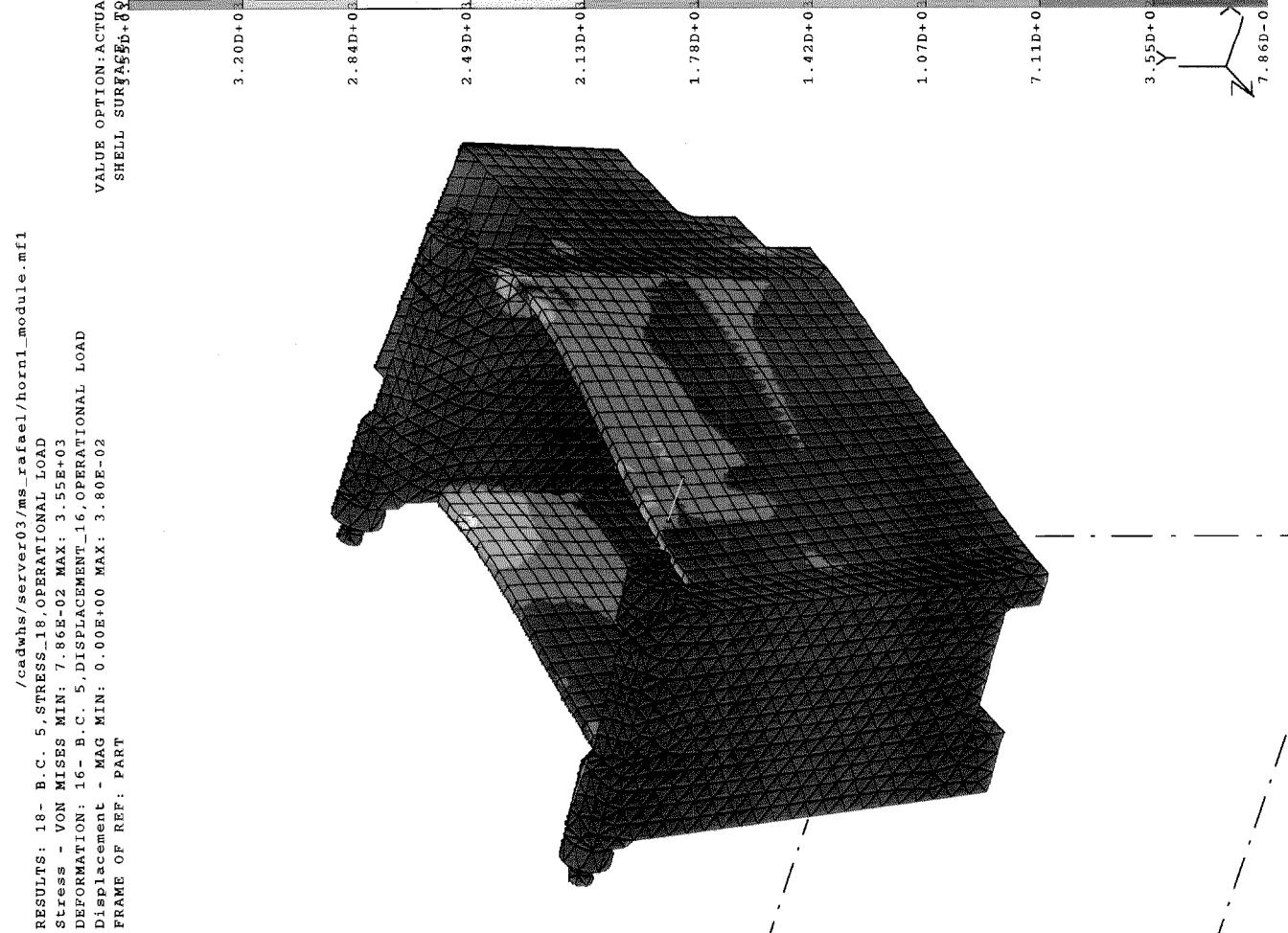
Database: /cadwhs/server03/ms_rafael/horn1_module.mf1

View : 1, 1

Task : Post Processing

Model: module_w_ss_slb

Active Study: DEFAULT FE STUDY



I-DEAS 8 m4: PARTICLE PHYSICS DIVISION : USER.rafael : /cadwhs/server03/ms_ra

Database: /cadwhs/server03/ms_rafael/horn1_module.mfi

View : 1, 1

Task : Post Processing

Model: module_w_ss_slb

Active Study: DEFAULT FE STUDY

10-Dec-01 14:47:13

Units : IN

Display : none, none

Model/Part Bin: Main

Parent Part: module_w_ss_slb

/cadwhs/server03/ms_rafael/horn1_module.mfi

RESULTS: 20 - B.C. 6 ,NORMAL_MODE 1,DISPLACEMENT_20

MODE: 1 BUCKLING LOAD FACTOR: 91.00848

Displacement - MAG MIN: 0.00E+00 MAX: 5.10E+00

DEFORMATION: 20 - B.C. 6 ,NORMAL_MODE 1,DISPLACEMENT_20

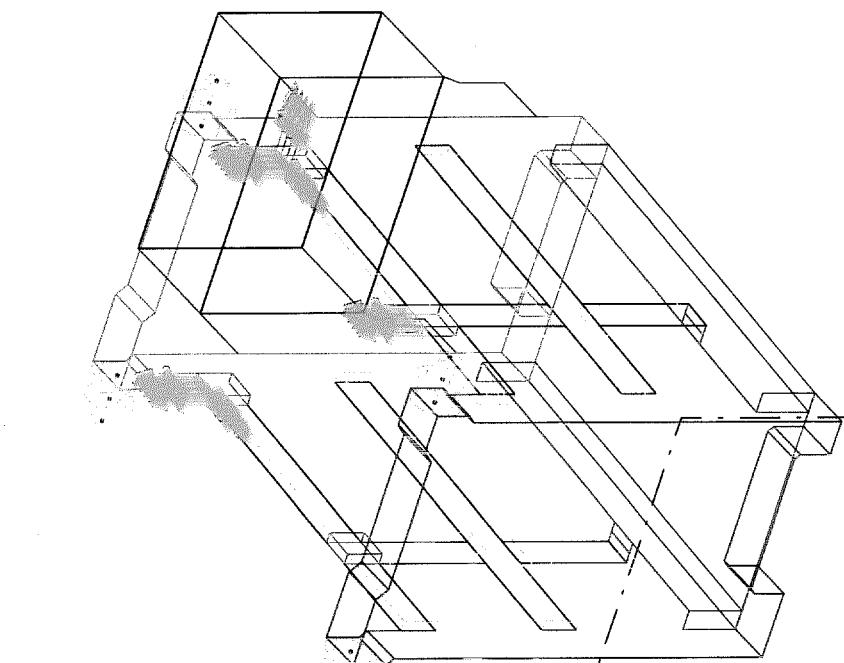
MODE: 1 BUCKLING LOAD FACTOR: 91.00848

Displacement - MAG MIN: 0.00E+00 MAX: 5.10E+00

FRAME OF REF: PART

VALUE OPTION:ACTUAL

5.10D+0



X
Y
Z

/cadwhs/server03/ms_rafael/horn1_module.mfi

RESULTS: 20 - B.C. 6 ,NORMAL_MODE 1,DISPLACEMENT_20

MODE: 1 BUCKLING LOAD FACTOR: 91.00848

Displacement - MAG MIN: 0.00E+00 MAX: 5.10E+00

DEFORMATION: 20 - B.C. 6 ,NORMAL_MODE 1,DISPLACEMENT_20

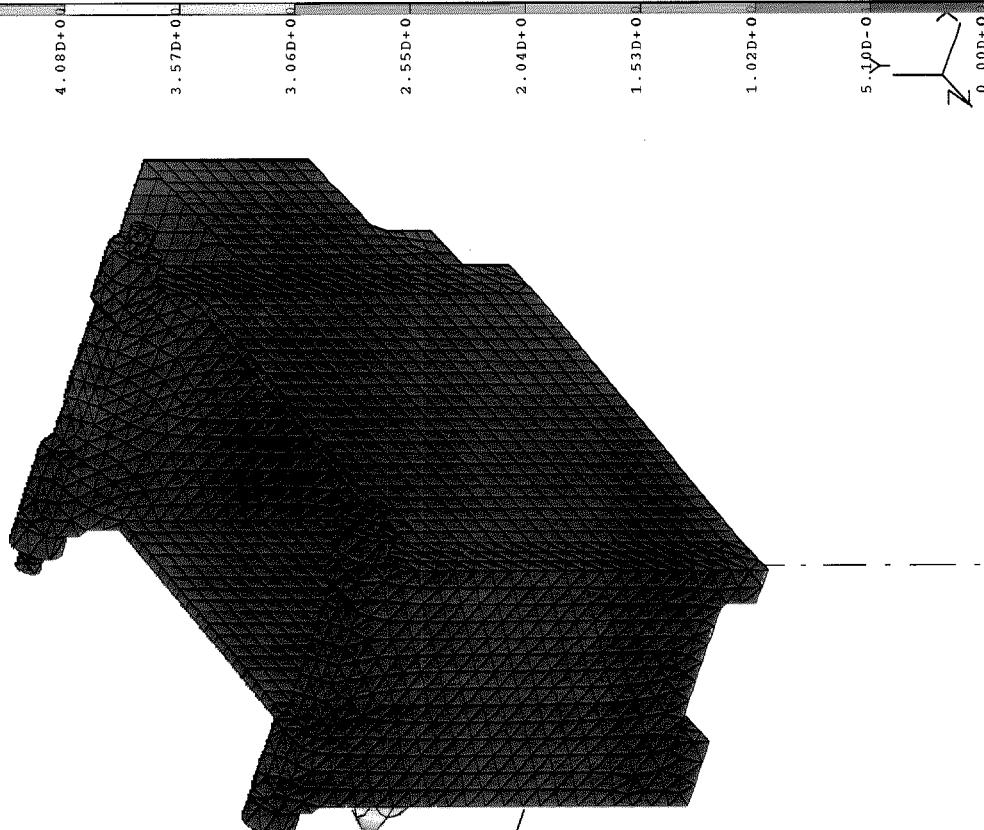
MODE: 1 BUCKLING LOAD FACTOR: 91.00848

Displacement - MAG MIN: 0.00E+00 MAX: 5.10E+00

FRAME OF REF: PART

VALUE OPTION:ACTUAL

5.10D+0



2.3. Analysis Of Connections

2.3.1 Welded Connections

According to the ANSI/ASME B30.20-1985 "Bellow-the-Hook Lifting Devices" item 20-1.2.2(a), all welding shall be in accordance with ANSI/AWS D1.1. AWS D1.1 determines allowable stresses also in accordance with the AISC code.

The lowest allowable stresses specified are for shear; $.3F_{E_{XXX}}$ or $.4F_y$. EXXXX minimum specified is E70XX and Fy minimum is 32 ksi. Hence, the minimum values would be:

- $.3F_{E_{XXX}} = 21.0 \text{ ksi}$
- $.4F_y = 12.8 \text{ ksi}$

Thus it is conservative to assume:

- $F_{\text{allowable}} = 12.8 \text{ ksi}$.

It should be noted that, in hand calculations, shear is not combined with normal stresses in bending of *members* because these two kinds of stresses are present in different parts of the members [1]. However, in *welds* under off-plane bending, both kinds of stresses may be present in the same region. So, they should be vectorially added.

The method used for calculation of stresses in welds in this note is the elastic vector analysis. For simplicity, the maximum load in any of the tubular joints (which happens in joint 1) was applied to the weakest joint (either 13, 14, 15 or 16) and analyzed.

The other joints analyzed were the one between the flange and the "modtops" and the one between the 10-inch block and the strip line box.

The stresses are less than 1/3 of the allowable stress of 12.8 ksi. The "coated" model was not used since the joints with the highest stresses were not located at the 10-inch plates.

All welds were sized to be equal or larger than the minimum size from AWS D1.1, considering the parts to be joined. See drawings for fabrication notes.

[1]See Roark and Young, Formulas for Stress and Strain, 6th ed., p.97 and Shigley and Mischke, Mechanical Engineering Design, 5th ed., p.51.

I-DEAS 8 m4: PARTICLE PHYSICS DIVISION : USER.rafael : /cadwhs/server03/ms_ra

Database: /cadwhs/server03/ms_rafael/horn1_module.mfl

View : VIENI (modified)

Task : Post Processing

Model: model_w_coat

Active Design: DEFAULT FE STUDY

/cadwhs/server03/ms_rafael/horn1_module.mfl

RESULTS: 3- B.C. 1. STRESS_3. OPERATIONAL LOAD
STRES - VON MISES MIN: 3.78E-01 MAX: 4.38E-03
DEFORMATION: 1- B.C. 1.DISPLACEMENT_1. OPERATIONAL LOAD
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 3.15E-02
FRAME OF REF: PART

4.38E-03

11-Dec-01 17:59:14

Units : IN

Display : No stored Option

Model/Part Bin: Main

Parent Part: model_w_coat

VALUE OPTION: ACTUAL
SHELL SURFACE: TOP
4.38E-03

3.95D+03

3.51D+03

3.08D+03

2.64D+03

2.21D+03

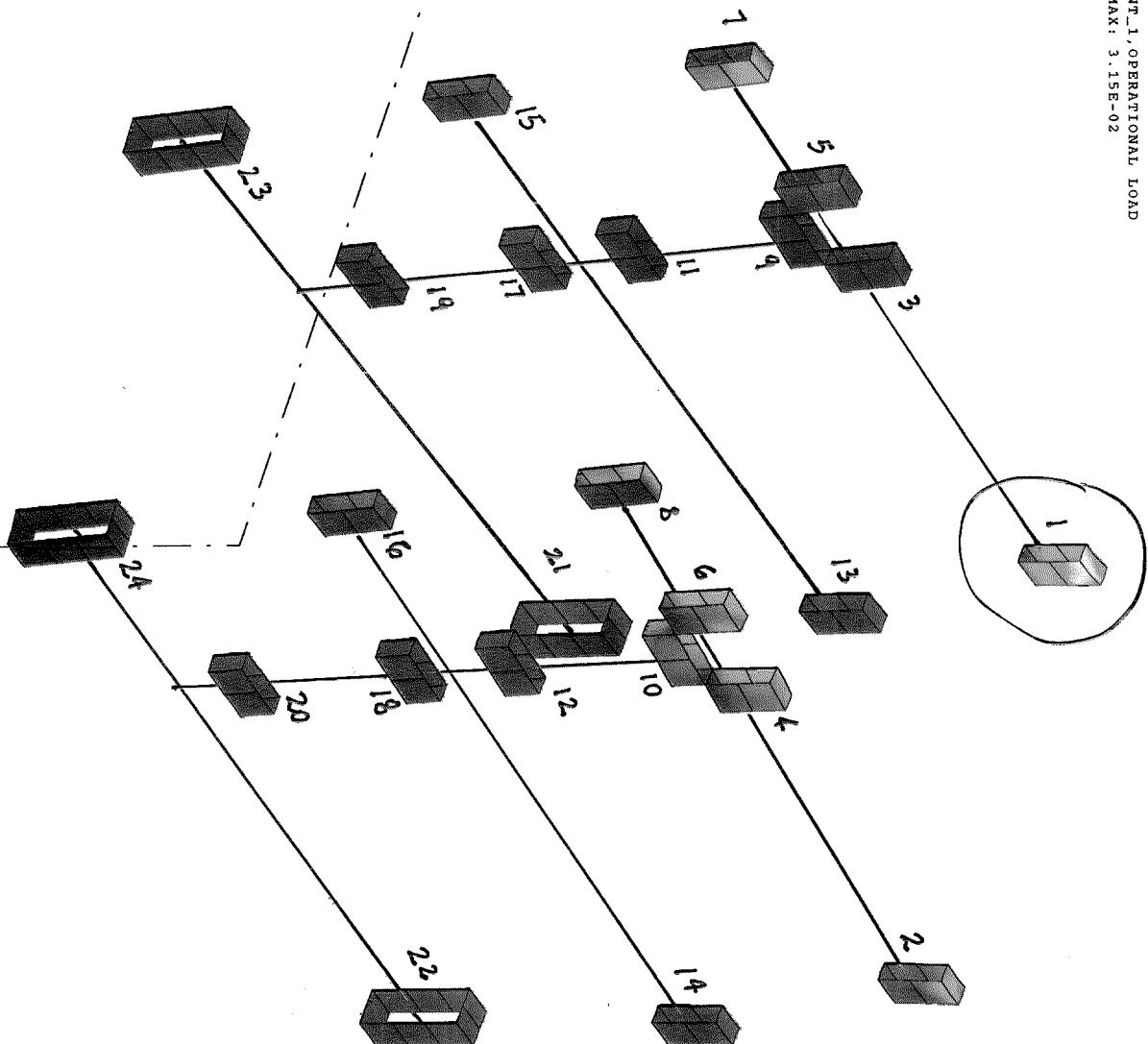
1.78D+03

1.34D+03

9.07D+02

4.72D+02

3.78D+01



joint1_node_forces.xls

I-DEAS 8 m4: Simulation 13-Dec-01 11:37:51

/cadwbs/server03/ms_rafael/horn1_module.mf1

Joint 1 forces

Group ID : None

Result Set : 19 - B.C. 5,ELEMENT FORCE_19,OPERATIONAL LOA

Function Dataset : Current

Report Type : XY - Graph Units : IN

Result Type : ELEMENT FORCE

Surface Type : Top

Frame of Reference: Part

Data Component: Magnitude

Frame of Reference: Part

Data Component: X-Component

Frame of Reference: Part

Data Component: Y-Component

Frame of Reference: Part

Data Component: Z-Component

Frame of Reference: Part

Data Component: RX-Component

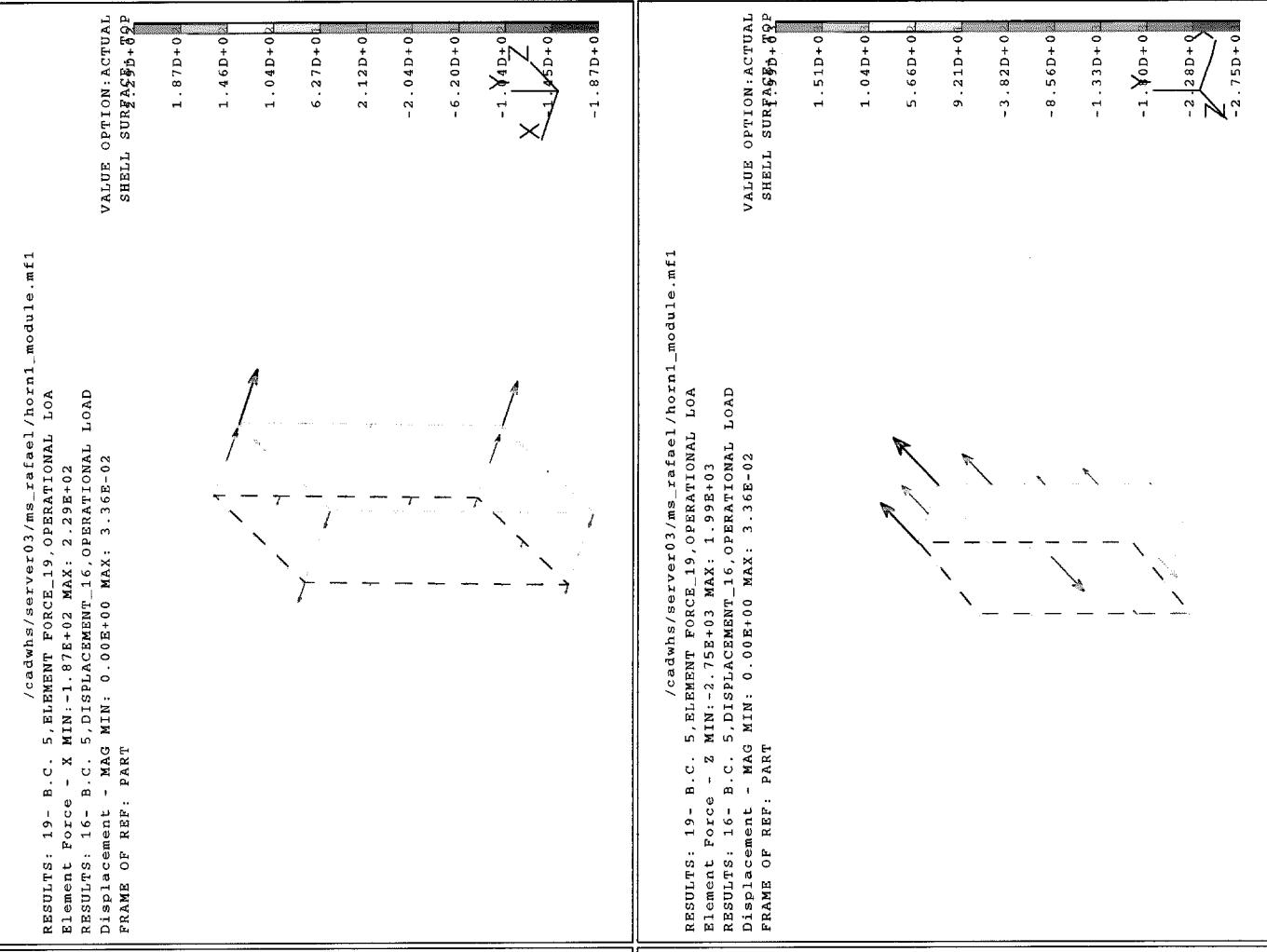
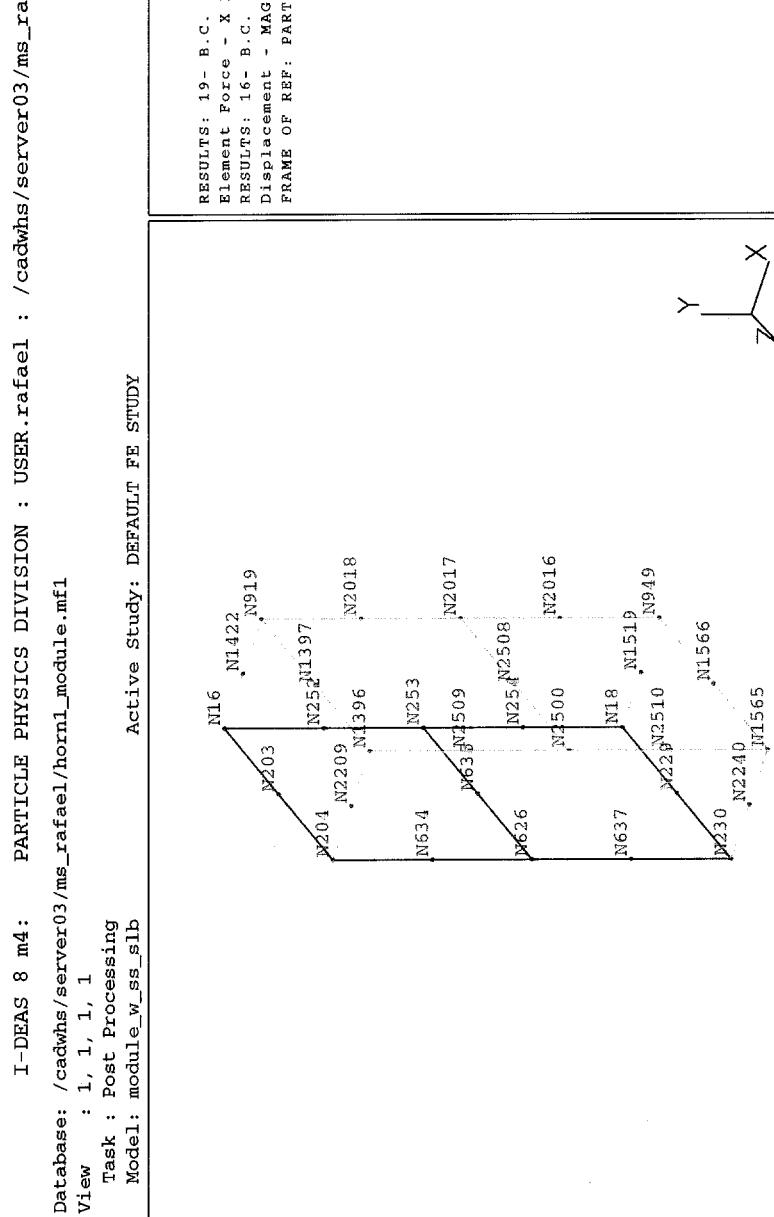
Frame of Reference: Part

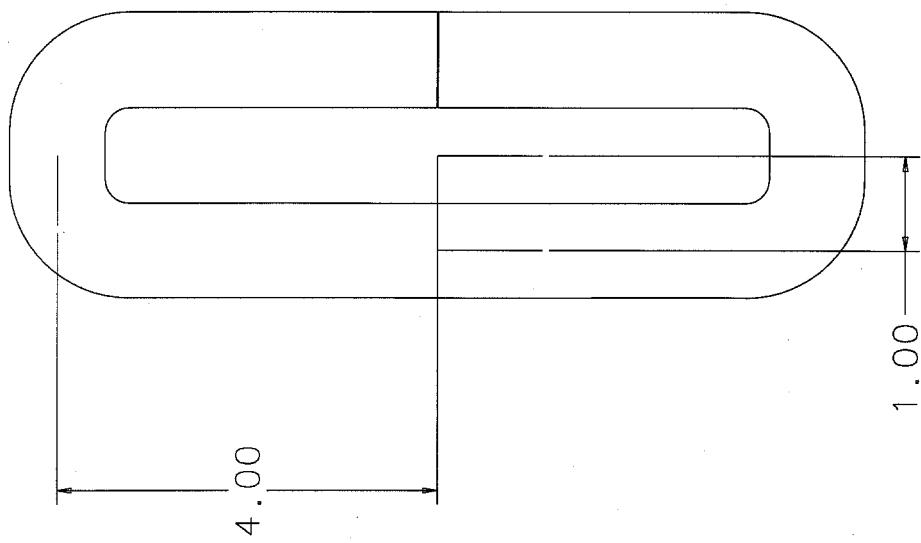
Data Component: RY-Component

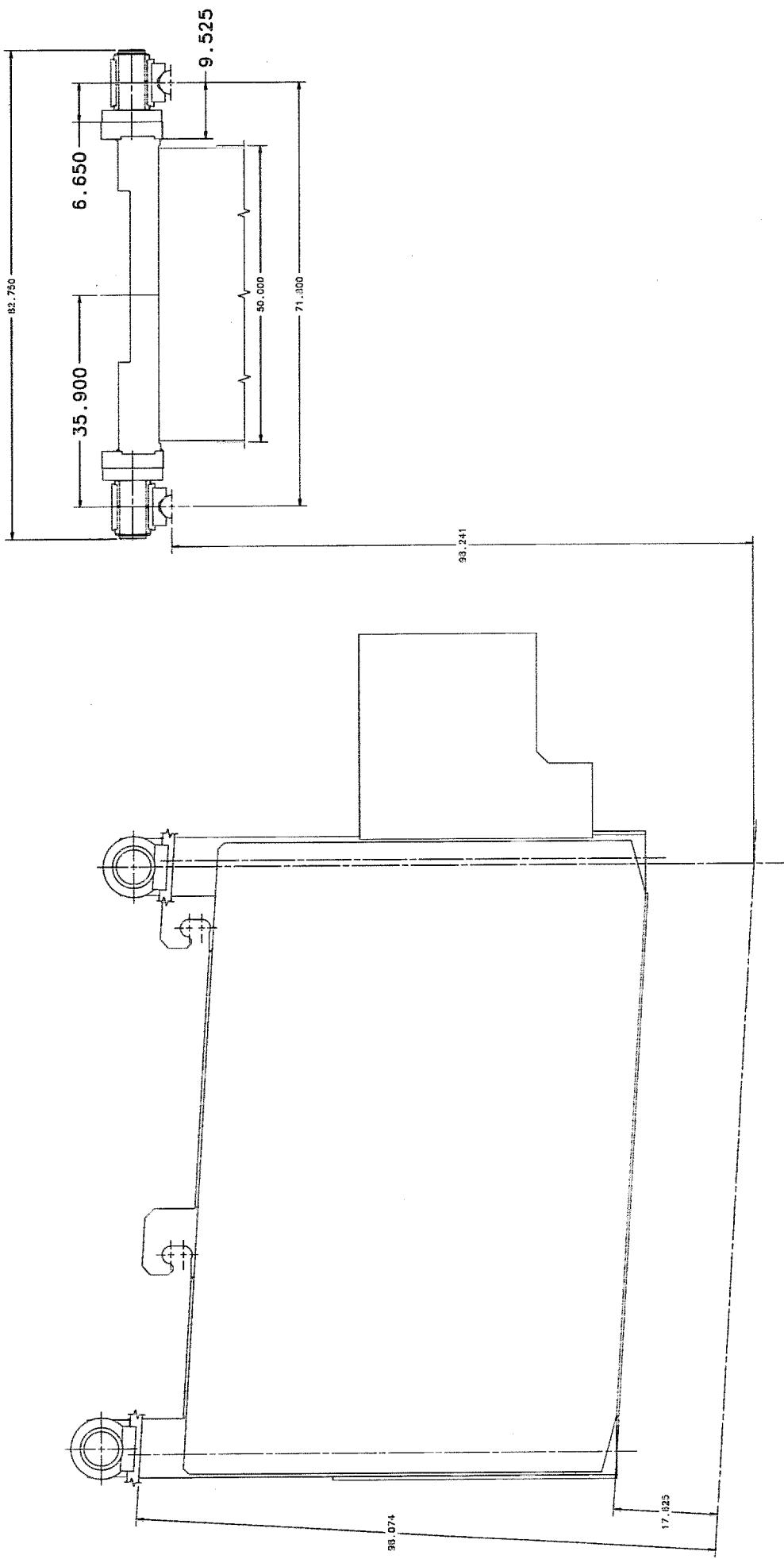
Frame of Reference: Part

Data Component: RZ-Component

Node	X-Comp	Y-Comp	Z-Comp	RX-Comp	RY-Comp	RZ-Comp
16	0	5760	-1539	0	0	0
18	0	0	0	0	0	0
252	0	0	0	0	0	0
253	0	0	0	0	0	0
254	0	0	0	0	0	0
919	0	3866	-2504	0	0	0
949	0	0	0	0	0	0
1422	0	402	-1630	0	0	0
1519	0	0	0	0	0	0
2016	0	0	0	0	0	0
2017	0	0	0	0	0	0
2018	0	0	0	0	0	0
Totals:	0	10027	-5673	0	0	0

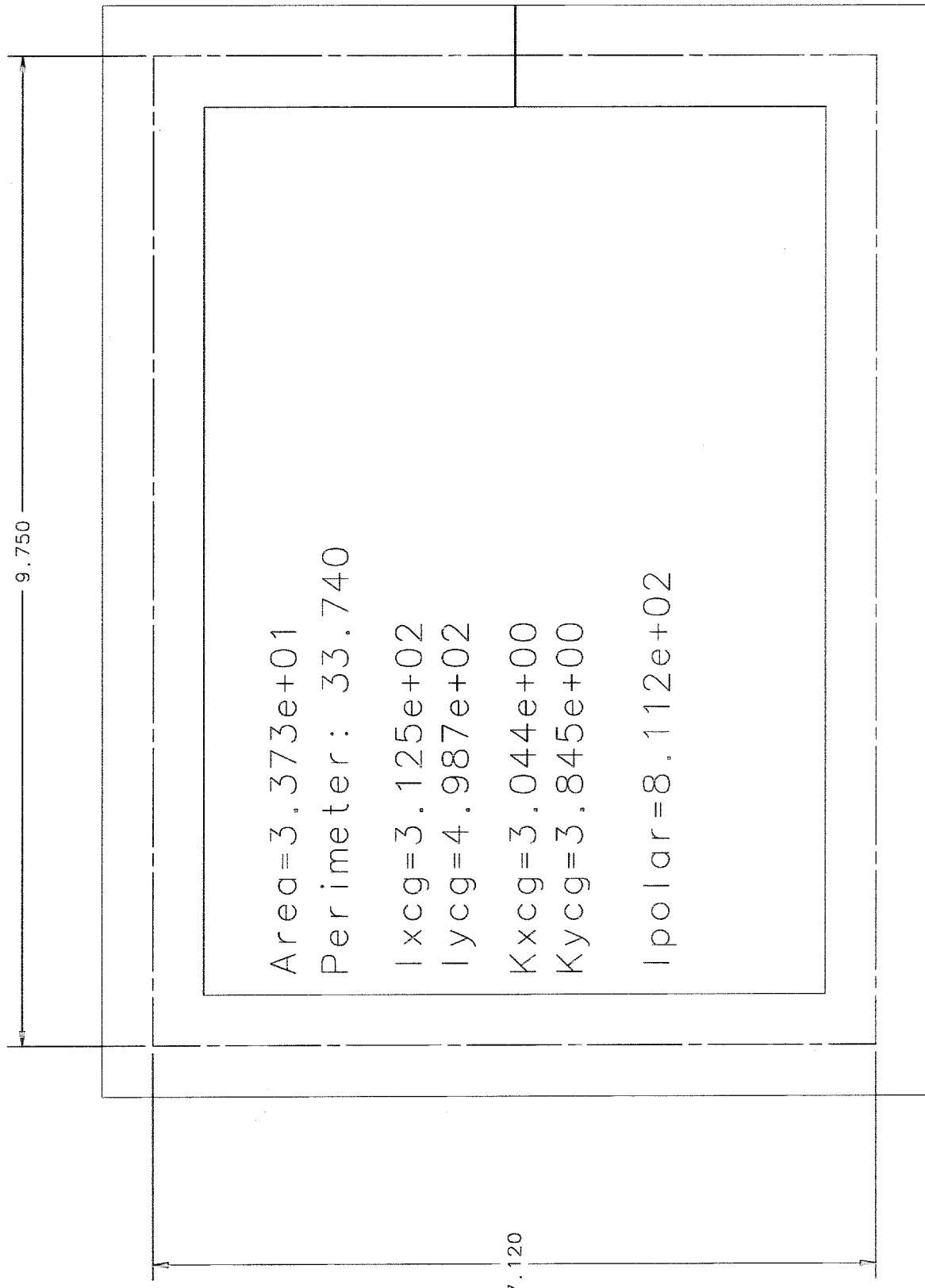






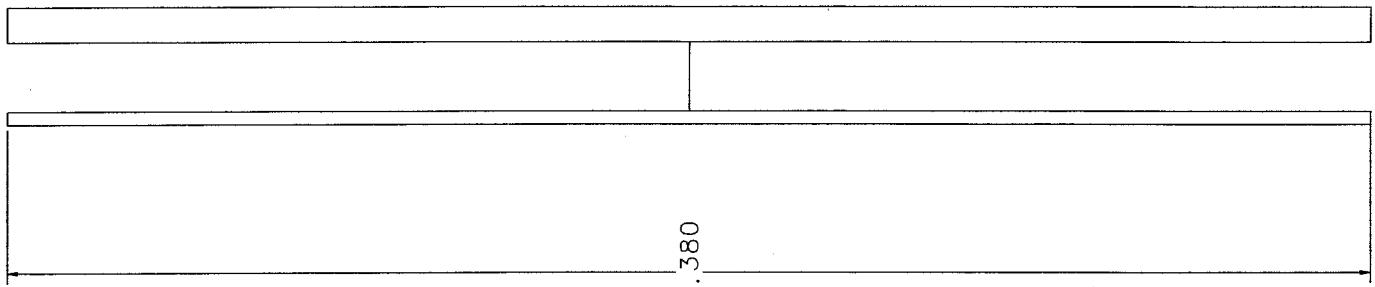
WELDS SUMMARY TABLE

A	B	C	D
1 Analysis Of Tubular Welded Joints	Units	Comment	Value
2 Joint	-	Highest load on weakest joint	1
3 Joint type	-	For design purposes	Tee
4 Weld type	-	-	Fillet
5 Base metals yield strength	Fy (ksi)	Minimum, ASTM A36, 10 inches thick	32.00
6 Allowable Stress	(ksi)	0.4 . Fy, from AWS and AISC for shear	12.80
7 Depth or leg	(in)	From geometry	0.38
8 Eff. throat	(in)	(leg) ^ (1/2)	0.27
9 Length	(in)	From geometry	18.70
10 Rw	(kips/in)	Eff. throat . Allowable stress	3.39
11 Ix	(in ⁴ /in)	Ixcg from I-DEAS	130.30
12 ly	(in ⁴ /in)	Iycg from I-DEAS	17.60
13 Ip	(in ⁴ /in)	Ipolar = Ixcg + Iycg	147.90
14 xcg	(in)	From geometry	1.00
15 ycg	(in)	From geometry	4.00
16 Sx	(in ³ /in)	Ix / ycg	32.58
17 Sy	(in ³ /in)	ly / xcg	17.60
18 Jx	(in ³ /in)	Ip / ycg	36.98
19 Jy	(in ³ /in)	Ip / xcg	147.90
20 Lx	(kips)	Total X load from I-DEAS	0.00
21 Ly1	(kips)	From I-DEAS	5.76
22 Ly2	(kips)	From I-DEAS	0.40
23 Ly3	(kips)	From I-DEAS	3.87
24 Ly	(kips)	Ly1 + Ly2 + Ly3	10.03
25 Lz1	(kips)	From I-DEAS	1.54
26 Lz2	(kips)	From I-DEAS	1.63
27 Lz3	(kips)	From I-DEAS	2.50
28 Lz	(kips)	Lz1 + Lz2 + Lz3	5.67
29 axy1,2,3	(in)	X lever arms to loads Ly1, Ly2 and Ly3	0.00
30 axz1	(in)	X lever arm to load Lz1	4.00
31 axz2	(in)	X lever arm to load Lz2	4.00
32 axz3	(in)	X lever arm to load Lz3	4.00
33 ayx1,2,3	(in)	Y lever arms to loads Lx1, Lx2 and Ly3	0.00
34 ayz1	(in)	Y lever arm to load Lz1	1.00
35 ayz2	(in)	Y lever arm to load Lz2	0.00
36 ayz3	(in)	Y lever arm to load Lz3	1.00
37 azx1,2,3	(in)	Z lever arms to loads Lx1, Lx2 and Lx3	0.00
38 azy1	(in)	Z lever arm to load Ly1	1.00
39 azy2	(in)	Z lever arm to load Ly2	0.00
40 azy3	(in)	Z lever arm to load Ly3	1.00
41 axz1 . Lz1	(kips-in)	-	6.2
42 axz2 . Lz2	(kips-in)	-	6.5
43 axz3 . Lz3	(kips-in)	-	10.0
44 ayz1 . Lz1	(kips-in)	-	1.5
45 ayz3 . Lz3	(kips-in)	-	-2.5
46 azy1 . Ly1	(kips-in)	-	-5.8
47 azy3 . Ly3	(kips-in)	-	3.9
48 Mx	(kips-in)	$\Sigma(Lyi . axyi) + \Sigma(Lzi . axzi)$	22.69
49 My	(kips-in)	$\Sigma(Lxi . aysi) + \Sigma(Lzi . ayz)$	-0.97
50 Mz	(kips-in)	$\Sigma(Lxi . azxi) + \Sigma(Lyi . azyi)$	-1.89
51 sx	(kips/in)	Lx / Length	0.00
52 sy	(kips/in)	Ly / Length	0.54
53 sz	(kips/in)	Lz / Length	0.30
54 Rzx	(kips/in)	Mx / Sx	0.70
55 Rzy	(kips/in)	My / Sy	-0.05
56 Rx	(kips/in)	Mz / Jx	-0.05
57 Ry	(kips/in)	Mz / Jy	-0.01
58 Fx (total)	(kips/in)	sx + Rx	-0.05
59 Fy (total)	(kips/in)	sy + Ry	0.52
60 Fz (total)	(kips/in)	sz + Rzx + Rzy	0.95
61 Vector Sum	(kips/in)	{ [(Fx) ^ 2] + [(Fy) ^ 2] + [(Fz) ^ 2] } ^ (1/2)	1.08
62 Vector Sum / Rw	-	-	0.32
63 Base metal yield strength / Vector Sum	-	-	7.84



WELDS SUMMARY TABLE

	A	B	C	D
1	Analysis Of "Modtops" Welded Joints	Units	Comment	Value
2	Joint	-	-	2
3	Joint type	-	For design purposes	Tee
4	Weld type	-	-	Fillet
5	Base metals yield strength	Fy (ksi)	Minimum, ASTM A36, 10 inches thick	32.00
6	Allowable Stress	(ksi)	0.4 . Fy, from AWS and AISC for shear	12.80
7	Depth or leg	(in)	From geometry	0.50
8	Eff. throat	(in)	(leg) ^ (1/2)	0.35
9	Length	(in)	From geometry	33.74
10	Rw	(kips/in)	Eff. throat . Allowable stress	4.53
11	Iz	(in ⁴ /in)	Ixcg from I-DEAS	312.50
12	Iy	(in ⁴ /in)	Iycg from I-DEAS	498.70
13	Ip	(in ⁴ /in)	Ipolar = Ixcg + Iycg	811.20
14	zcg	(in)	From geometry	4.88
15	y cg	(in)	From geometry	3.56
16	Sz	(in ³ /in)	Iz / y cg	87.78
17	Sy	(in ³ /in)	Iy / zcg	102.30
18	Jz	(in ³ /in)	Ip / y cg	227.87
19	Jy	(in ³ /in)	Ip / zcg	166.40
20	Lx	(kips)	Total X load from I-DEAS	5.40
21	Ly	(kips)	Total Y load from I-DEAS	28.50
22	Lz	(kips)	Total Z load from I-DEAS	3.40
23	Ix	(in)	lever arm	9.53
24	My	(kips-in)	Ix . Ly	271.61
25	Mz	(kips-in)	Ix . Lz	32.40
26	sx	(kips/in)	Lx / Length	0.16
27	sy	(kips/in)	Ly / Length	0.84
28	sz	(kips/in)	Lz / Length	0.10
29	Ry	(kips/in)	My / Sy	2.66
30	Rz	(kips/in)	Mz / Sz	0.37
31	Fx (total)	(kips/in)	sx	0.16
32	Fy (total)	(kips/in)	sy + Ry	3.50
33	Fz (total)	(kips/in)	sz + Rz	0.47
34	Vector Sum	(kips/in)	{ [(Fx) ^ 2] + [(Fy) ^ 2] + [(Fz) ^ 2] } ^ (1/2)	3.53
35	Vector Sum / Rw	-	-	0.78
36	Base metal yield strength / Vector Sum	-	-	3.20



39 . 380

Area=5.417e+01

| xcg=6.998e+03
| ycg=8.104e+01

Kx cg=1.137e+01
Ky cg=1.223e+00

| polar=7.079e+03

WELDS SUMMARY TABLE

	A	B	C	D
1	Analysis Of Strip Lne to 10-inch Block Welded Joints	Units	Comment	Value
2	Joint	-	-	3
3	Joint type	-	For design purposes	Tee
4	Weld type	-	-	Fillet
5	Base metals yield strength	Fy (ksi)	Minimum, ASTM A36, 10 inches thick	32.00
6	Allowable Stress	(ksi)	0.4 . Fy, from AWS and AISC for shear	12.80
7	Narrower leg (considering both welds 3/8" instead of 1" and 3/8")	(in)	From geometry	0.38
8	Eff. throat	(in)	(leg) ^ (1/2)	0.27
9	Length	(in)	From geometry	39.38
10	Rw	(kips/in)	Eff. throat . Allowable stress	3.39
11	Ix	(in ⁴ /in)	Ixcg from I-DEAS	6998.00
12	Iy	(in ⁴ /in)	Iycg from I-DEAS	81.04
13	Ip	(in ⁴ /in)	Ipolar = Ixcg + Iycg	7079.04
14	xcg	(in)	From geometry	1.34
15	y cg	(in)	From geometry	19.69
16	Sx	(in ³ /in)	Ix / ycg	355.41
17	Sy	(in ³ /in)	Iy / xcg	14.65
18	Jx	(in ³ /in)	Ip / ycg	359.52
19	Jy	(in ³ /in)	Ip / xcg	5268.12
20	Ly	(kips)	Total Y load	17.35
21	Iz	(in)	lever arm	24.75
22	Mx	(kips-in)	Ly . Iz	429.44
23	sy	(kips/in)	Ly / Length	0.44
24	Rx	(kips/in)	Mx / Sx	1.21
25	Vector Sum	(kips/in)	{ [(sy) ^ 2] + [(Rx) ^ 2] } ^ (1/2)	1.29
26	Vector Sum / Rw	-	-	0.38
27	Base metal yield strength / Vector Sum	-	-	6.60

2.3.1 Bolted Connections

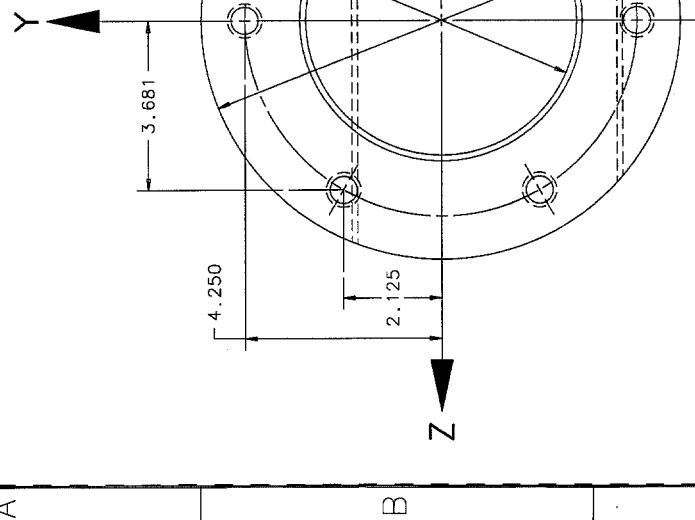
There are 2 bolted connections. One is between the "modtops" and the 10-inch plate. The other is in the shaft coupling. The analyses were done with calculations based on "Steel Structures: Design and Behavior", Salmon and Johnson, Harper Collins, 3rd ed., 1990, chap 4.15, Shear and Tension From Eccentric Loading, p. 183-190.

They are also in accordance with AISC/ASD, 9th ed., Chapter J, except that the material of the screws is not listed by the code. For the approved carbon steels, standard size holes, in slip-critical connections, the AISC/ASD code specifies a minimum allowable of .33 of tensile strength in tension and .14 of tensile strength in shear. These factors were applied to the material of the screws selected, ASTM A-574 alloy steel.

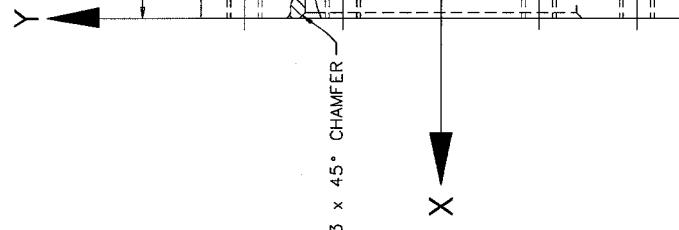
The specified screws are Unbrako 3/4"-10 UNRC x 3" long and Unbrako 1"-8 UNRC x 7" long, socket head cap screws. From Unbrako catalog, the recommended seating torques are 500 ft-lbs and 1042 ft-lb respectively.

The loading was obtained from the FEA, boundary condition set 1, downstream, which is the most severe case for these joints. There are combined tension and shear in these slip-critical joints. The calculations show that both joints are loaded below their allowed safe loads.

4



3



A

B

C

D

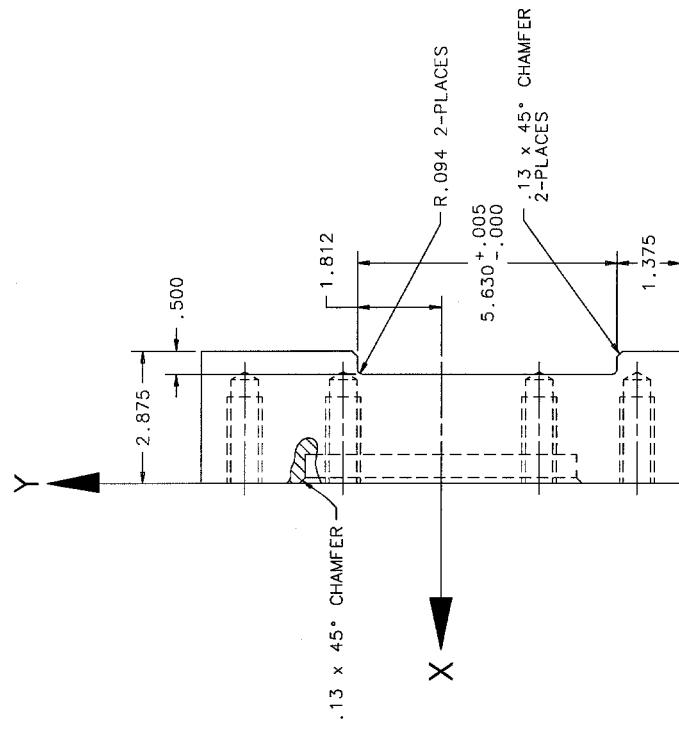
A

B

C

D

PRELIMINARY



ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
			APPROVED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX	XXX	ANGLES	R. SILVA 02-14-01
±.03	±.005	± 5°	B. CYKO 02-14-01
			CHECKED
1.	BREAK ALL SHARP EDGES	USED ON	
2.	0.15 MAX DO NOT SCALE DRNG.		
3.	WITH ANSI Y14.5M-1982		
4.	SALL DIMENSIONS ARE IN		
	INCHES.		
125	MAX. ALL MACHINED SURFACES		

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
PARTS LIST			
		UNLESS OTHERWISE SPECIFIED	ORIGINATOR
.XX			

Support Shaft Bolted Joint

File: Support_Shift_bolts.mcd

Calculations based on Steel Structures: Design and Behavior, Salmon and Johnson, Harper Collins, 3rd ed., 1990, and in accordance with AISC/ASD, Chapter J (*).

Chap 4.15, Shear and Tension From Eccentric Loading, p. 183-190.

- Slip-critical Connection;
- Size of holes: standard, 13/16";
- Threads not excluded from shear planes;
- Bolt specification: Unbrako 3/4"-10 UNRC x 3" long, A- 574 socket head cap screw. From Unbrako catalog (minimum values):

Ultimate Strength (ksi): $F_u := 180$

Yield Strength (ksi): $F_y := 155$

Shear Strength (kips): $S_s := 47.7$

From Unbrako catalog, recommended torque: 6,000 in-lbs (500 ft-lbs).

(*) For the approved carbon steels, standard size holes, in slip-critical connections, the AISC/ASD code specifies a minimum allowable of .33 of tensile strength in tension and .14 of tensile strength in shear. Applying these factors to ASTM A-574 alloy steel gives:

Allowable in tensile: $F_t := .33 \cdot F_u$ $F_t = 59.4$

Allowable in shear: $F_v := .14 \cdot F_u$ $F_v = 25.2$

Screw diameter (in): $d := \frac{3}{4}$

Screw area (in²): $A_b := \frac{\pi}{4} \cdot d^2$ $A_b = 0.4$

Allowable shear load (kips): $R_v := F_v \cdot A_b$ $R_v = 11.1$

Allowable tensile load (kips): $R_t := F_t \cdot A_b$ $R_t = 26.2$

Maximum reactions from FEA, boundary condition set 1, other side, downstream (kips):

$$P_x := 5.4$$

$$P_y := 28.5$$

$$P_z := -3.4$$

Lever arm, from geometry (in):

$$l_x := 6.655$$

Number of screws:

$$m := 6$$

Tension (in X) from off plane bending around Y:

Bending moment, from FEA (in-kips): $M_y := -P_z \cdot l_x$ $M_y = 22.6$

Calculation of $\Sigma z 2$: $\Sigma z 2 := 4 \cdot 3.681^2$ $\Sigma z 2 = 54.2$

$$z_{\max} := 3.681$$

Max. tension on bolt (kips): $T_{x1} := \frac{M_y \cdot z_{\max}}{\Sigma z 2}$ $T_{x1} = 1.5$

Tension (in X) from off plane bending around Z:

Bending moment, from FEA (in-kips): $M_z := P_y \cdot l_x$ $M_z = 189.7$

Calculation of $\Sigma y 2$: $\Sigma y 2 := 2 \cdot 4.25^2 + 4 \cdot 2.125^2$ $\Sigma y 2 = 54.2$

$$y_{\max} := 4.25$$

Max. tension on bolt (kips): $T_{x2} := \frac{M_z \cdot y_{\max}}{\Sigma y 2}$ $T_{x2} = 14.9$

Maximum tensile load (in X):

Total tensile load (kips): $T_t := T_{x1} + T_{x2} + \frac{P_x}{m}$ $T_t = 17.3$

$R_t (26.2) > T_t (17.3) \Rightarrow \text{OK.}$

Direct Y shear:

Shear (kips): $V_y := \frac{P_y}{m}$ $V_y = 4.8$

Direct Z shear:

Shear (kips): $V_z := \frac{P_z}{m}$ $V_z = -0.6$

Total Shear load:

Total shear load (kips): $V_t := \sqrt{V_y^2 + V_z^2}$ $V_t = 4.8$

$R_v (11.1) > V_t (4.8) \Rightarrow \text{OK.}$

Combined Tension and Shear in Slip-critical Joints:

Minimum pre-tension, tb. J3.7, p.5-77 (kips): $T_b := .7 \cdot F_u \cdot A_b$ $T_b = 55.7$

Maximum tensile stress (ksi): $f_t := \frac{T_t}{A_b}$ $f_t = 39.2$

Allowable shear (J.6, p. 5-74): $f_v := F_v \cdot \left(1 - f_t \cdot \frac{A_b}{T_b}\right)$ $f_v = 17.4$

Allowable shear load (kips): $R_{v'} := f_v \cdot A_b$ $R_{v'} = 7.7$

$R_{v'} (7.7) > V_t (4.8) \Rightarrow \text{OK.}$

Conclusion:

$R_t (26.2) > T_t (17.3)$, $R_v (11.1) > V_t (4.8)$ and $R_{v'} (7.7) > V_t (4.8) \Rightarrow$ bolts are OK.

Joint: Support Shaft

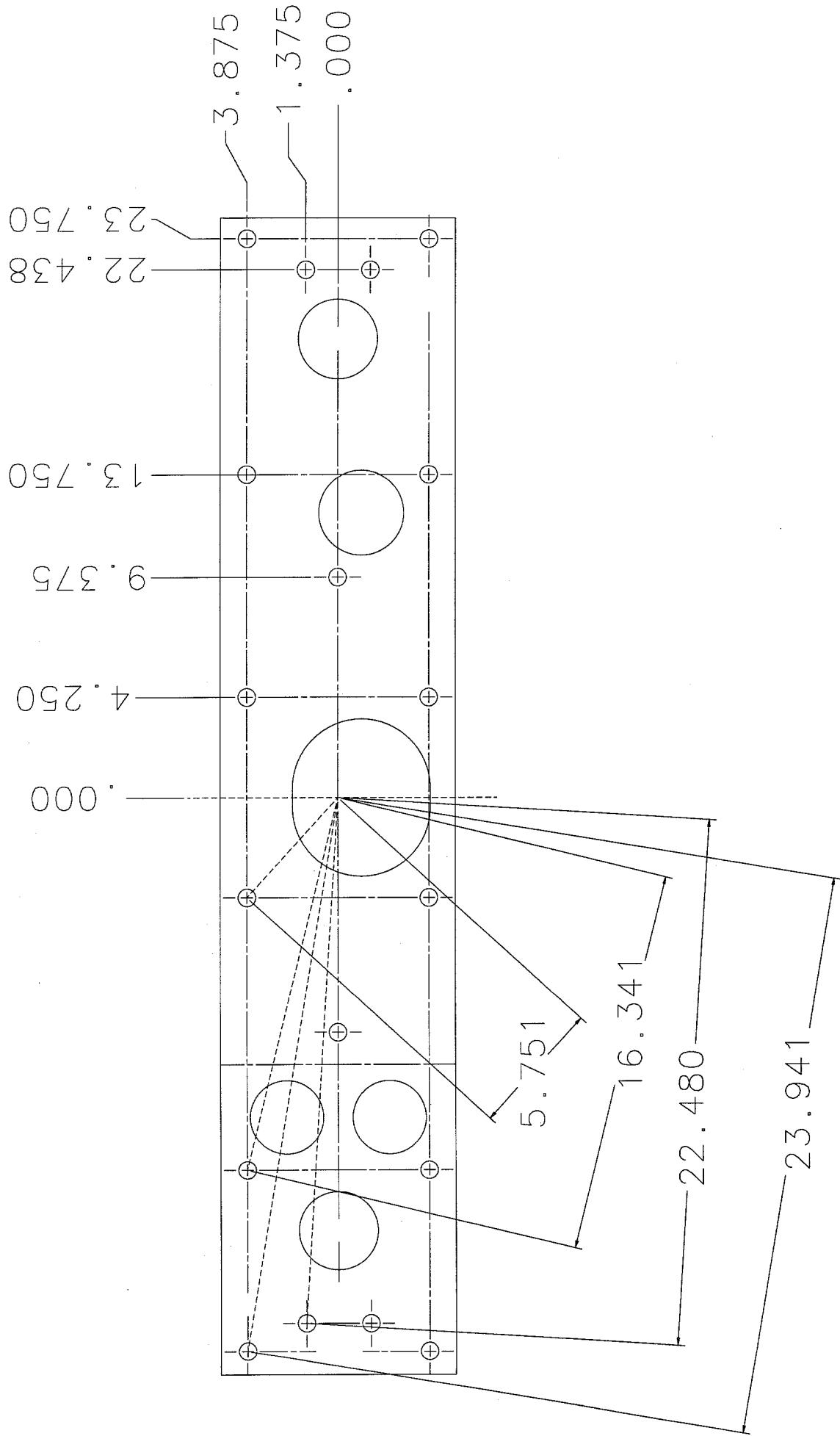
File: Torque_Support_Shift.mcd

Torque Required

The calculations are based on the methodology presented by Shigley & Mischke, Chapter 8.
 For permanent connections, the pre-load is based on ASD recommendations (Table 4, p.5-274) of tension required of 70% of tensile strength plus 5% for torque wrenches (total of 78.5%).
 For reusable connections, the pre-load is based on Shigley & Mischke, Chapter 8, p. 349, equations 8-25 or 8-26, representing 75% of the proof load or, in the absence of that, 85% of the yield strength.

Type of connection assumed in this case:**Permanent**.

Bolt Tensile/Proof/Yield Stress (ksi):	$F_a := 180$		
Req. Bolt Tension, ASD/Shigley (ksi):	$R_b := .7 \cdot F_a$	$R_b = 126.0$	
Torque Factor, ($Z_n=.2, Blk=.3$), p.347:	$K := .2$		
Major Screw Diameter (in):	$d := \frac{3}{4}$		
Pitch (threads/in):	$n := 10$		
Grip Threaded Length (in):	$l_t := 1.788$		
Grip Unthreaded Length (in):	$l_d := 1.212$		
Bolt Elastic Modulus (ksi):	$E_b := 29000$		
External Tensile Load (kips):	$P := 17.3$		
Threaded Member Elastic Modulus (ksi):	$E_t := 29000$		
Threaded Member Thickness (in):	$t_t := 1.788$		
Unthreaded Member Elastic Modulus (ksi):	$E_u := 29000$		
Unthreaded Member Thickness (in):	$t_u := 1.212$		
Washer Diameter [$D \approx 1.5 \cdot d$] (in):	$D := 1.25$		
Half-Apex Angle ($^\circ$):	$a := 30$		
$\alpha := \frac{\pi}{180} \cdot a$	$\alpha = 0.52$	$Ad := \frac{\pi}{4} \cdot d^2$	$Ad = 0.44$
$At := .7854 \cdot \left(d - \frac{.9743}{n} \right)^2$	$At = 0.334$	$kb := \frac{Ad \cdot At \cdot E_b}{Ad \cdot l_t + At \cdot l_d}$	$kb = 3.58 \times 10^3$
$kt := \frac{\pi \cdot E_t \cdot d \cdot \tan(\alpha)}{\ln \left[\left[\frac{(2 \cdot t_t \cdot \tan(\alpha) + D - d) \cdot (D + d)}{(2 \cdot t_t \cdot \tan(\alpha) + D + d) \cdot (D - d)} \right] \right]}$		$ku := \frac{\pi \cdot E_u \cdot d \cdot \tan(\alpha)}{\ln \left[\left[\frac{(2 \cdot t_u \cdot \tan(\alpha) + D - d) \cdot (D + d)}{(2 \cdot t_u \cdot \tan(\alpha) + D + d) \cdot (D - d)} \right] \right]}$	
$kt = 42612.76$		$ku = 49051.71$	
$KM := \frac{1}{\frac{1}{kt} + \frac{1}{ku}}$	$KM = 2.28 \times 10^4$	$C := \frac{kb}{kb + KM}$	$C = 0.14$
Total Bolt Load from Req. Bolt Tension (kips):	$F_b := R_b \cdot At$	$F_b = 42.1$	
Preload - Clamping Force (kips):	$F_i := F_b - C \cdot P$	$F_i = 39.8$	
Torque Required (ft-lb):	$T := \frac{K \cdot F_i \cdot 1000 \cdot d}{12}$	$T = 497$	



Modtops Bolted Joint

File: Modtops_bolts.mcd

Calculations based on Steel Structures: Design and Behavior, Salmon and Johnson, Harper Collins, 3rd ed., 1990, and in accordance with AISC/ASD, Chapter J (*).

Chap 4.15, Shear and Tension From Eccentric Loading, p. 183-190.

- Slip-critical Connection;
- Size of holes: standard, 1 1/16";
- Threads not excluded from shear planes;
- Bolt specification: Unbrako 1"-8 UNRC x 7" long, A- 574 socket head cap screw.
From Unbrako catalog (minimum values):

Ultimate Strength (ksi): $F_u := 180$

Yield Strength (ksi): $F_y := 155$

Shear Strength (kips): $S_s := 84.8$

From Unbrako catalog, recommended torque: 12,500 in-lbs (1042 ft-lbs).

(*) For the approved carbon steels, standard size holes, in slip-critical connections, the AISC/ASD code specifies a minimum allowable of .33 of tensile strength in tension and .14 of tensile strength in shear. Applying these factors to ASTM A-574 alloy steel gives:

Allowable in tensile: $F_t := .33 \cdot F_u$ $F_t = 59.4$

Allowable in shear: $F_v := .14 \cdot F_u$ $F_v = 25.2$

Screw diameter (in): $d := 1$

Screw area (in²): $A_b := \frac{\pi}{4} \cdot d^2$ $A_b = 0.8$

Allowable shear load (kips): $R_v := F_v \cdot A_b$ $R_v = 19.8$

Allowable tensile load (kips): $R_t := F_t \cdot A_b$ $R_t = 46.7$

Maximum reactions from FEA, boundary condition set 1, downstream (kips):

$P_x := 5.4$

$P_{ysls} := 13.6$ $P_{yos} := 28.5$ $P_y := P_{ysls} + P_{yos}$ $P_y = 42.1$

$P_{zsks} := 3.4$ $P_{zos} := -3.4$ $P_z := P_{zsks} + P_{zos}$ $P_z = 0.0$

Lever arms, from geometry (in):

$$l_x := 35.9$$

Number of screws:

$$m := 18$$

Tension (in Y) from off plane bending around Z:

Bending moment, from FEA (in-kips): $M_z := (P_{yos} - P_{ysls}) \cdot l_x$ $M_z = 534.9$

Calculation of Σx^2 : $\Sigma x^2 := 4 \cdot (4.25^2 + 13.75^2 + 22.438^2 + 23.75^2) + 2 \cdot 9.375^2$

$$\Sigma x^2 = 5274.4$$

$$x_{max} := 23.75$$

Max. tension on bolt (kips): $T_y := \frac{M_z \cdot x_{max}}{\Sigma x^2}$ $T_y = 2.4$

Maximum tensile load:

Total tensile load (kips): $T_t := T_y + \frac{P_y}{m}$ $T_t = 4.7$

$$R_t (46.7) > T_t (4.7) \Rightarrow \text{OK.}$$

Shear from in plane moment around Y:

Bending moment, from FEA (in-kips): $M_y := (P_{zsds} - P_{zos}) \cdot l_x$ $M_y = 244.1$

Calculation of Σd^2 : $\Sigma d^2 := 4 \cdot (5.751^2 + 16.341^2 + 22.48^2 + 23.941^2) + 2 \cdot 9.375^2$

$$\Sigma d^2 = 5690.3$$

$$d_{max} := 23.941$$

Max. tension on bolt (kips): $V_{xz} := \frac{M_y \cdot d_{max}}{\Sigma d^2}$ $V_{xz} = 1.0$

Direct X shear:

Shear (kips): $V_x := \frac{P_x}{m}$ $V_x = 0.3$

Direct Z shear:

Shear (kips): $V_z := \frac{P_{zsds} + P_{zos}}{m}$ $V_z = 0.0$

Total Shear load:

Total shear load (kips): $V_t := \sqrt{V_x^2 + V_{xz}^2}$ $V_t = 1.1$

$R_v (19.8) > V_t (1.1) \Rightarrow \text{OK.}$

Combined Tension and Shear in Slip-critical Joints:

Minimum pre-tension, tb. J3.7, p.5-77 (kips): $T_b := .7 \cdot F_u \cdot A_b$ $T_b = 99.0$

Maximum tensile stress (ksi): $f_t := \frac{T_t}{A_b}$ $f_t = 6.0$

Allowable shear (J.6, p. 5-74): $f_v := F_v \cdot \left(1 - f_t \cdot \frac{A_b}{T_b}\right)$ $f_v = 24.0$

Allowable shear load (kips): $R_{v'} := f_v \cdot A_b$ $R_{v'} = 18.8$

$R_{v'} (18.8) > V_t (1.1) \Rightarrow \text{OK.}$

Conclusion:

$R_t (46.7) > T_t (4.7)$, $R_v (19.8) > V_t (1.1)$ and $R_{v'} (18.8) > V_t (1.1) \Rightarrow$ bolts are **OK.**

Joint: Modtops

File: Torque_Modtops.mcd

Torque Required

The calculations are based on the methodology presented by Shigley & Mischke, Chapter 8. For permanent connections, the pre-load is based on ASD recommendations (Table 4, p.5-274) of tension required of 70% of tensile strength plus 5% for torque wrenches (total of 78.5%). For reusable connections, the pre-load is based on Shigley & Mischke, Chapter 8, p. 349, equations 8-25 or 8-26, representing 75% of the proof load or, in the absence of that, 85% of the yield strength.

Type of connection assumed in this case:**Permanent**.

Bolt Tensile/Proof/Yield Stress (ksi):	$F_a := 180$	
Req. Bolt Tension, ASD/Shigley (ksi):	$R_b := .7 \cdot F_a$	$R_b = 126.0$
Torque Factor, ($Z_n=2, Blk=.3$), p.347:	$K := .2$	
Major Screw Diameter (in):	$d := 1$	
Pitch (threads/in):	$n := 8$	
Grip Threaded Length (in):	$l_t := 2$	
Grip Unthreaded Length (in):	$l_d := 5$	
Bolt Elastic Modulus (ksi):	$E_b := 29000$	
External Tensile Load (kips):	$P := 4.7$	
Threaded Member Elastic Modulus (ksi):	$E_t := 29000$	
Threaded Member Thickness (in):	$t_t := 2$	
Unthreaded Member Elastic Modulus (ksi):	$E_u := 29000$	
Unthreaded Member Thickness (in):	$t_u := 5$	
Washer Diameter [$D \geq 1.5 \cdot d$] (in):	$D := 1.5$	
Half-Apex Angle (°):	$a := 30$	
$\alpha := \frac{\pi}{180} \cdot a$	$\alpha = 0.52$	$Ad := \frac{\pi}{4} \cdot d^2$
$At := .7854 \cdot \left(d - \frac{.9743}{n} \right)^2$	$At = 0.606$	$Ad = 0.79$
$k_t := \frac{\pi \cdot E_t \cdot d \cdot \tan(\alpha)}{\ln \left[\left[\frac{(2 \cdot t_t \cdot \tan(\alpha) + D - d) \cdot (D + d)}{(2 \cdot t_t \cdot \tan(\alpha) + D + d) \cdot (D - d)} \right] \right]}$	$k_t = 49074.81$	$kb := \frac{Ad \cdot At \cdot E_b}{Ad \cdot l_t + At \cdot l_d}$
$KM := \frac{1}{\frac{1}{kt} + \frac{1}{ku}}$	$KM = 2.19 \times 10^4$	$kb = 3.00 \times 10^3$
Total Bolt Load from Req. Bolt Tension (kips):	$F_b := R_b \cdot At$	$F_b = 76.3$
Preload - Clamping Force (kips):	$F_i := F_b - C \cdot P$	$F_i = 75.8$
Torque Required (ft-lb):	$T := \frac{K \cdot F_i \cdot 1000 \cdot d}{12}$	$T = 1263$

Technical Specification for NuMI Horn 1 Module - Frame

Rafael Silva

W.B.S. 1.1.2
November 14th, 2001

1. Parts

Parts as detailed on Fermi National Accelerator Laboratory PPD/NuMI Horn 1 Module drawings and all items and drawings called out therein. The drawing numbers and their respective titles are:

8875.111-MB-406456 - Middle Hook
8875.111-MB-406457 - End Hook
8875.111-MC-406352 - Frame Tube "A"
8875.111-MC-406353 - Frame Tube "B"
8875.111-MC-406354 - Frame Tube "C"
8875.111-MC-406355 - Frame Tube "D"
8875.111-MC-406371 - Side Plate R.H.
8875.111-MC-406372 - Side Plate L.H.
8875.111-MC-406377 - Inside Panel "A"
8875.111-MC-406378 - Inside Panel "B"
8875.111-MC-406454 - Frame Tube "E"
8875.111-MC-406507 - Shielding Plate D.S.
8875.111-MC-406508 - Shielding Plate U.S.
8875.111-MD-406351 - Side Cover
8875.111-ME-406239 - Module Cover and Panel Weldment
8875.111-ME-406240 - Module Block D.S. and
8875.111-ME-406241 - Module Block U.S.
8875.111-ME-406455 - Module Weldment
8875.111-ME-406491 - Module Machining, Sheets 1, 2 and 3
8875.111-ME-406505 - Module Grouting and Painting

Drawings with stamp "Approved for fabrication" will be issued on contract award.

2. Fabrication and Inspection

All structural steel parts shall be fabricated in strict accordance with the *Code of Standard Practice for Steel Buildings and Bridges* of the American Institute of Steel Construction (AISC), 1986, unless otherwise noted in any of the contractual documents. All welds shall be in strict accordance with the Structural Welding Code - Steel, of the American Welding Society, AWS D1.1-2000, unless otherwise noted in any of the contractual documents.

Material ASTM A710 Grade A Class 3 to be used in the fabrication of the four hooks, parts shown on drawing numbers 8875.111-MB-406456 - Middle Hook and 8875.111-MB-406457 - End Hook, will be provided by Fermilab.

All welds must be visually inspected. All welds involving rectangular tubing included on drawing 8875.111-ME-406455 - Module Weldment, must be certified to have been inspected according to the latest ASTM edition of the applicable standard for:

- **Liquid Penetrant**, with no relevant indication of discontinuity;
or
- **Magnetic Particles**, with no relevant indication of discontinuity.

In addition to that, all full penetration welds (with backing) on drawing 8875.111-ME-406455 - Module Weldment must be certified to have been inspected according to the latest ASTM edition of the applicable standard for:

- **Ultrasonic Testing**, with no internal reflections with response greater than a 1/64". Maximum void fraction not to exceed 2% by volume;
or
- **X-Ray** (or Gamma Ray), no internal defects larger than 1/64" allowed. Maximum void fraction not to exceed 2% by volume.

All relevant indications should be repaired and re-inspected as above. Absolutely no cracks allowed.

Inspection certification of the dimensions on drawing 8875.111-ME-406491 - Module Machining, Sheets 1, 2 and 3 required as deliverable.

A *Fermilab* inspector will inspect the fabrication at the vendor's facility. Acceptance is contingent to *Fermilab* inspector's verification of full compliance with contractual documents, required tolerances and procedures.

3. Grouting

As indicated on drawing number 8875.111-ME-406505 - Module Grouting and Painting, the sidewalls (inside rectangular tubing and in between them) of the structure will be filled with grout. The vendor may elect to sub-contract or not to undertake this part of the job.

4. Surface Condition

All parts of the assembly that are not machined nor concealed shall be:

- thoroughly *cleaned* of all scale, rust and dirt per specifications of the Steel Structure Painting Council (SSPC) "Surface Preparation Specification No. 3, (SP-3), Power Tool Cleaning" or better. Particular attention should be given to weld seams and joints.

All non-concealed parts of the assembly shall be:

- thoroughly *cleaned* of all oil, grease, salts, and contaminants per specifications of the Steel Structure Painting Council (SSPC) "Surface Preparation Specification No. 1, (SP-1), Solvent Cleaning".

As indicated on drawing number 8875.111-ME-406505 - Module Grouting and Painting, all carbon steel parts of the assembly that are not concealed, with the exception of machined holes and indicated surfaces, shall be painted. These parts shall be:

- *primed* with synthetic rust-inhibiting ferrous metal primer;
- *painted* with two coats of synthetic finishing paint.

Primer and paint should be of one of the following kinds: epoxy resin, phenolic, melamine-formaldehyde, polyurethane or polyester. Primer Lord Aeroglaze 9924 and finishing paint Lord Aeroglaze 276 Polyurethane is preferable and recommended. Primer shall be completely dry before topcoating and paint manufacturer instructions shall be followed. Color shall be white.

Stainless Steel parts are not to be painted. All carbon steel parts that are not to be painted shall be properly wrapped and protected in order to preserve the cleanliness obtained with the above-mentioned cleaning processes and to minimize rust formation.

5. Shipping

Structure shall be transported properly secured and the load bearing areas should be the lowest horizontal surfaces of the 10-inch thick ASTM A36 carbon steel blocks. These blocks should be in the vertical orientation during transport. Load bearing areas must be reasonably protected against damage. Structure should be protected from the weather and dirt. Details must be approved by Fermilab's inspector prior to shipping and alternatives may be submitted to Fermilab for approval.